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DEVELOPMENT AND TESTING
OF AN UNMANNED AIR VEHICLE
TELEMETRY SYSTEM

by
Kevin Thomas Wilhelm
September 1991

Thesis Advisor:

Richard M. Howard

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92-05054



92 2 26 083

Unclassified

Security Classification of this page

REPORT DOCUMENTATION PAGE

1a Report Security Classification Unclassified			1b Restrictive Markings		
2a Security Classification Authority			3 Distribution Availability of Report		
2b Declassification/Downgrading Schedule			Approved for public release; distribution is unlimited.		
4 Performing Organization Report Number(s)			5 Monitoring Organization Report Number(s)		
6a Name of Performing Organization Naval Postgraduate School		6b Office Symbol (If Applicable) 67	7a Name of Monitoring Organization Naval Postgraduate School		
6c Address (city, state, and ZIP code) Monterey, CA 93943-5000			7b Address (city, state, and ZIP code) Monterey, CA 93943-5000		
8a Name of Funding/Sponsoring Organization		8b Office Symbol (If Applicable)	9 Procurement Instrument Identification Number		
8c Address (city, state, and ZIP code)			10 Source of Funding Numbers		
			Program Element Number Project No Task No Work Unit Accession No		
11 Title (Include Security Classification) DEVELOPMENT AND TESTING OF AN UNMANNED AIR VEHICLE TELEMETRY SYSTEM					
12 Personal Author(s) Wilhelm, Kevin T.					
13a Type of Report Master's Thesis		13b Time Covered From To		14 Date of Report (year, month, day) 1991, September 25	
				15 Page Count 83	
16 Supplementary Notation The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.					
17 Cosati Codes			18 Subject Terms (continue on reverse if necessary and identify by block number)		
Field	Group	Subgroup	UAV, RPV, Telemetry, Ducted-Fan, Instrumentation, Radio Control.		
19 Abstract (continue on reverse if necessary and identify by block number) Unmanned Air Vehicles (UAV's) provide a low-cost, low-maintenance, and effective platform upon which experimentation can be performed to validate conceptual aerodynamic ideas. However, the UAV flight test data acquisition process is complex and requires a reliable recording system for post-flight data analysis. The thrust of this thesis was the development, construction, and validation of a viable telemetry system for data gathering and processing. Major areas of focus were: integration of the telemetry into a 1/8 scale model, radio controlled F-16A airplane; telemetry circuitry optimization; recording and display of instrumented parameters; and data reduction techniques necessary to obtain useful information. A flight test was flown and data was gathered using a steady-heading side-slip maneuver to demonstrate successful integration of all supporting elements.					
20 Distribution/Availability of Abstract (X) unclassified/unlimited () same as report () DTIC users			21 Abstract Security Classification Unclassified		
22a Name of Responsible Individual Richard M. Howard			22b Telephone (Include Area code) (408) 646-2870		22c Office Symbol AA/Ho

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted
All other editions are obsolete

security classification of this page
Unclassified

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OF AN UNMANNED AIR VEHICLE
TELEMETRY SYSTEM

by

Kevin Thomas Wilhelm
Lieutenant Commander, United States Navy
B.S., United States Naval Academy, 1982

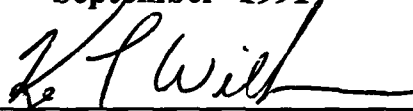
Submitted in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE IN AERONAUTICAL
ENGINEERING


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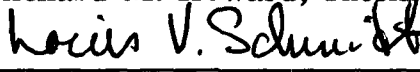
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ABSTRACT

Unmanned Air Vehicles (UAV's) provide a low-cost, low-maintenance, and effective platform upon which experimentation can be performed to validate conceptual aerodynamic ideas. However, the UAV flight test data acquisition process is complex and requires a reliable recording system for post-flight data analysis. The thrust of this thesis was the development, construction, and validation of a viable telemetry system for data gathering and processing. Major areas of focus were: integration of the telemetry into a 1/8-scale model, radio-controlled F-16A airplane; telemetry circuitry optimization; recording and display of instrumented parameters; and data reduction techniques necessary to obtain useful information. A test flight was flown and data were gathered using a steady-heading side-slip maneuver to demonstrate successful integration of all supporting elements.

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ACKNOWLEDGMENTS

There are many people who have as big a stake in this product as I do. Successful completion of this thesis was only possible because of the efforts of two individuals who continually contribute to the success of the faculty and students without recognition. I would like to express my personal thanks to Mr. Tom Christian and Mr. Don Meeks. Without Tom's help, my journey through the world of the "trons" would have been frustrating and endless. Without Don's help, I would still be wet-sanding the F-16 model and wondering where the ignition switch was to start the engine.

I commend Dr. Rick Howard's fore-sight and his stead-fast determination to make his idea work. His cheery attitude and easy demeanor enabled me to make it through the many ups and downs on this adventure without feeling nauseous.

Lastly, I would like to express my deepest appreciation to my wife Kim. Her patience, understanding, and support on the home-front made my job seem easy.

I. INTRODUCTION

In the world of airplane flight testing several major events are closely coupled to the observation, collection, and extraction of the flight test data. Real-time flight parameter observation is frequently necessary to ensure safe aerodynamic, structural, and human endurance limits are not exceeded. A complete understanding of complex flight dynamics frequently mandates precise post-flight data analysis of flight parameters too numerous to annotate by hand. In addition, final conclusions and recommendations concerning any test program need to be substantiated not only with qualitative information from the pilot, but with quantitative data from the airplane.

Onboard data gathering is one method of obtaining required flight data; however, space, accessibility, and weight limitations do not always permit the use of onboard data gathering equipment. The rigors of the flight test regime can also complicate onboard data collection by imposing "g" loadings, power requirements, and temperature extremes which substantially increase the cost of recording equipment. Furthermore, correct operation of data recording equipment is difficult to validate when the recorder is remotely located in the airplane or when recordings are to be made in Remotely Piloted Vehicles (RPV's).

The RPV's used by the Naval Postgraduate School Department of Aeronautics and Astronautics provide a demanding environment for any data collection equipment. They combine the problems of high vibration, very limited space, high "g" loadings, and limited payload on each flight. A ground-based recording system incorporating a telemetry (TM) data-link would avoid

many of the aforementioned pitfalls and could be of great assistance to the RPV researcher.

The scope of this thesis was to complete a seven-channel telemetry (TM) system and demonstrate its ability to provide useful data. Primary emphasis was placed on the construction of the airborne TM unit, integration of the TM into a radio-controlled (RC) 1/8-scale model F-16A airplane, construction of the ground-based TM receiving unit, development of data extraction methods to convert dc voltage recordings into meaningful forms, and flight test verification of total system operation.

II. BACKGROUND

A. TELEMETRY

The Naval Postgraduate School (NPS) has been investigating the concept of aircraft supermaneuverability through the work of the NPS Department of Aeronautics and Astronautics. In order to further its research, the Department chose to perform proof-of-concept demonstration flight testing utilizing model aircraft as testbeds. The nature of this testing required many flight maneuvers to be repeated several times with the aircraft in different configurations. This complicated the project because multiple flight parameters had to be observed for proper flight test conditions to be set, and since the model aircraft pilot could not be inside the aircraft itself, there had to be a way of getting the information from the aircraft to the pilot. Additionally, related projects demonstrated that the primary flight data recording device had to be isolated from the aircraft, since the recorder was found to be inaccurate when subjected to vibration or acceleration stresses [Ref. 1:p. 36]. In order to eliminate these problems, a decision was made to incorporate a telemetry system into the testing. However, the small size and light weight of the models coupled with a meager operating budget negated the use of any single commercial system and created the need for a unique telemetry system to be developed at the Naval Postgraduate School.

B. F-16 AIRPLANE

The 1/8-scale F-16 radio-controlled model was constructed and test flown prior to the beginning of this project. The airplane was composed of a pre-formed fiberglass fuselage with high-density foam wings, stabilators, and rudder.

Propulsion was provided by a Rossi 0.90-in³ glow-plug single piston engine which drove a six-inch diameter, five-bladed, ducted fan. Previous engine thrust tests demonstrated static thrust levels of 13.5-14.0 lbf at full power [Ref. 2:pp.10-13]. Model characteristics are presented in Table I.

TABLE I: F-16 MODEL CHARACTERISTICS

Characteristic	Dimension
Length	73 in
Wing Span	48 in
Mean Aerodynamic Chord	18.4 in
Wing Reference Area	777.6 in
Aspect Ratio	2.96
Leading Edge Sweep	40 deg
Taper Ratio	0.218
Empty Weight (w/telemetry)	14 lbs
Fuel Capacity	24 fl oz

III. CHOW-1G MODEL AIRCRAFT TELEMETRY SYSTEM

A. GENERAL

The CHOW-1G airborne telemetry system was designed to provide a stand-alone, compact, lightweight, mobile data transmission system for monitoring and recording Unmanned Air Vehicle (UAV) flight parameters. The system was comprised of two major subsystems: an airborne unit responsible for encoding and transmitting selected aircraft parameters; and a ground based unit responsible for receiving, decoding, recording, and displaying the aircraft parameters.

B. AIRBORNE SUBSYSTEM

The airborne subsystem was comprised of an encoder unit and a transmitter unit, as shown in Figure 1.

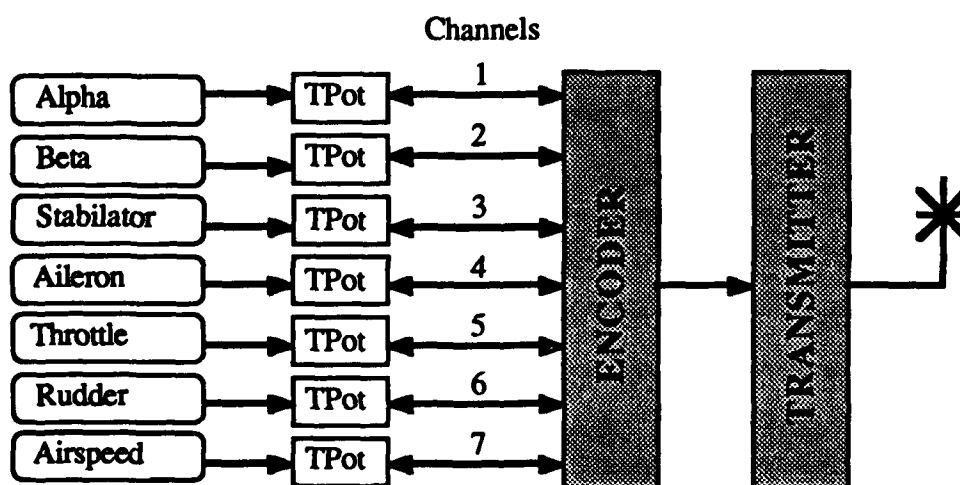


Figure 1: Airborne Subsystem Block Diagram

The combination was mounted in the cockpit section of the F-16A model, as shown in Figure 2, 18.25 in. aft of the airplane nose and measured 5.0 X 2.0 X 3.25 in. TM package weight (excluding wing-root battery) was 0.70 lbs.

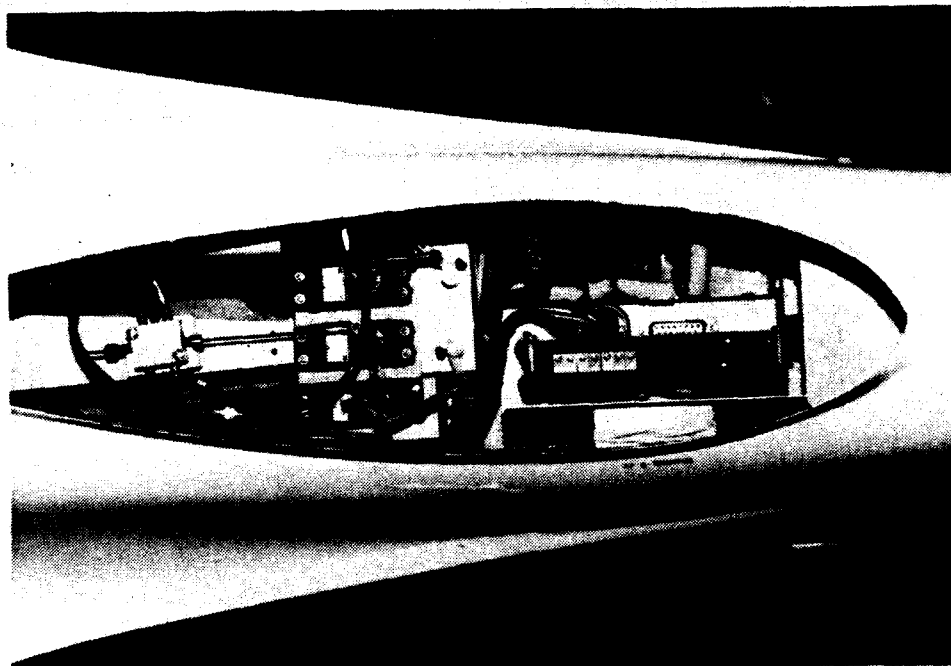


Figure 2: CHOW-1G Installation in the F-16A Model Airplane

1. Encoder Unit

The encoder unit consisted of a programmable resistor-capacitor encoder circuit purchased from Ace R/C, Inc. and designed to perform to the manufacturer's specifications listed in Table II. The encoder's block diagram is shown in Figure 3.

The integrated circuit (IC) multiplexer (NE5044) was responsible for converting the parallel direct current (DC) inputs from the control potentiometers into a single serial pulse width modulated output. Using the

components in Figure 3, the multiplexer functioned as a strobed voltage follower, accomplishing the modulation process using a dual linear ramp technique.[Ref. 3:p. 6]

TABLE II: RC ENCODER PERFORMANCE SPECIFICATIONS

Parameter	Specification
Modulation	Pulse width
Channels	Adjustable from 3 to 7
Pulse width	1.0 ms \pm .5 ms
Sample Rate (per channel)	Adjustable 40 to 100 Hz
Input Impedance (per channel)	Greater than 1M Ω
Power Requirements	9.6VDC 500 mAh NiCad battery
Power output	5.0 VDC regulated source

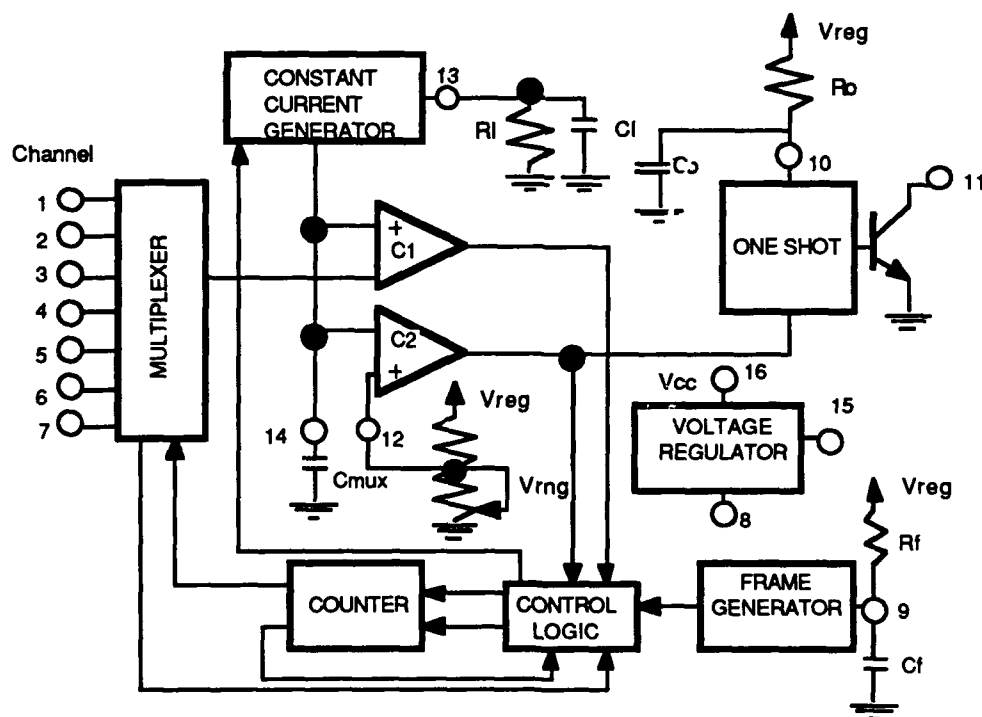


Figure 3: RC Encoder Circuit Diagram

The One-Shot generated a positive pulse at the beginning of each channel's sample. A constant current generator then charged and discharged the C_{mux} capacitor alternately while an external capacitor C_I maintained stability of the feedback loop. Two high gain comparators, C1 and C2, compared the voltage across C_{mux} with the multiplexer output and the range input voltage. They then provided the counter control logic which controlled the counter and current generator. Together these circuits were responsible for determining the duration/modulation of each individual pulse. The duration (in seconds) of each individual pulsewidth was driven by equation (1):

$$T_n = 4R_I (V_n - V_{range}) C_{mux} / V_{ref} \quad (1)$$

where the subscript "n" corresponds to any one of the seven input channels. The frame generator controlled the encoder time frame by generating a timing pulse at the end of each frame. It was operated in a fixed mode as an astable multivibrator whose period (in seconds) was determined by the values of the Frame RC network on the multiplexer and the relationship shown in equation (2):

$$T_f = 0.66 R_f C_f \quad (2)$$

The final result was an output pulse whose width was directly proportional to the DC voltage input, as shown in Figure 4. The sampling frequency (or frame rate, TF) was adjustable from 33 to 200 Hz by changing the factory configured external RC components, listed in Table III, attached to the encoder chip, shown in Figure 5. However, the preset sampling frequency of 48 Hz provided a 21 ms window and was deemed adequate for F-16 model testing.[Ref. 3:p. 6]

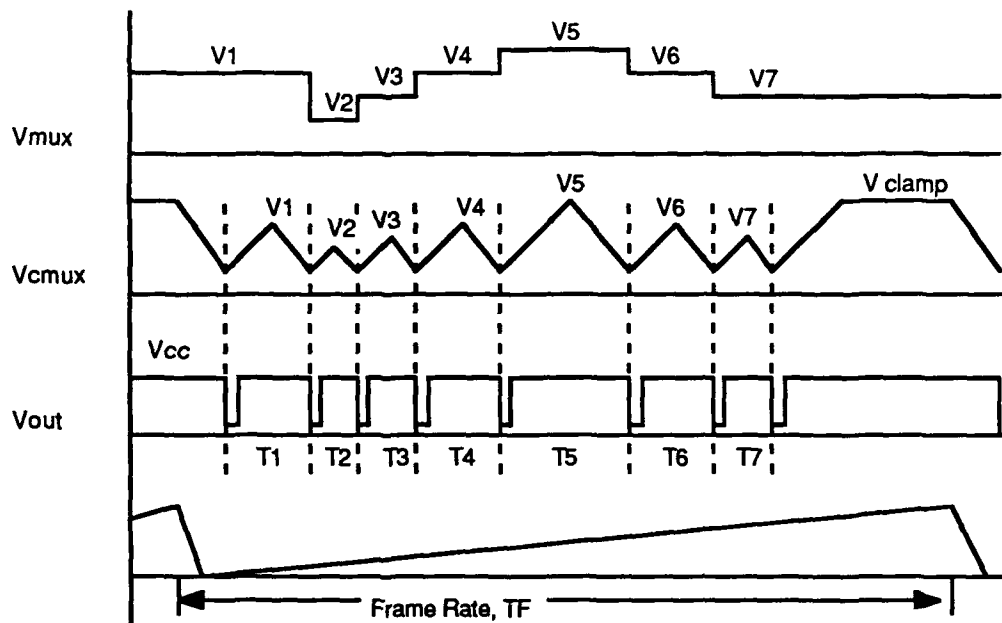


Figure 4: Encoder Timing Diagram

TABLE III: EXTERNAL CONFIGURATION OF NE5044 ENCODER

Component	Value	Component	Value
R_I	58.2 K Ω	C_o	0.01 μ f
C_I	0.047 μ f	R_f	330.0 K Ω
C_{mux}	0.047 μ f	C_f	1.0 μ f
V_{range}	1.0 VDC	V_{reg}	5.0 VDC
R_o	39.0 K Ω		

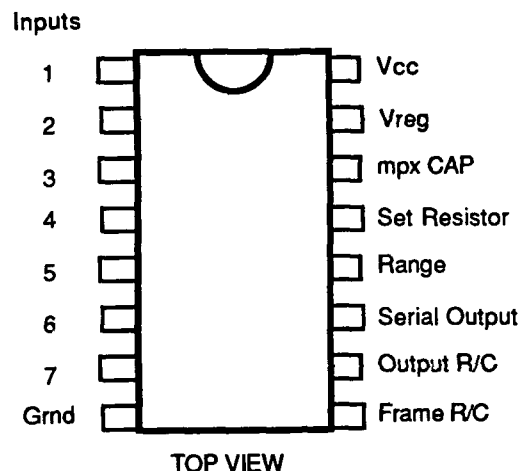


Figure 5: Encoder Circuitboard Pin Configuration

2. Transmitter Unit

The transmitter unit was also purchased from Ace R/C, Inc. The interaction of the transmitter components is depicted in Figure 6.

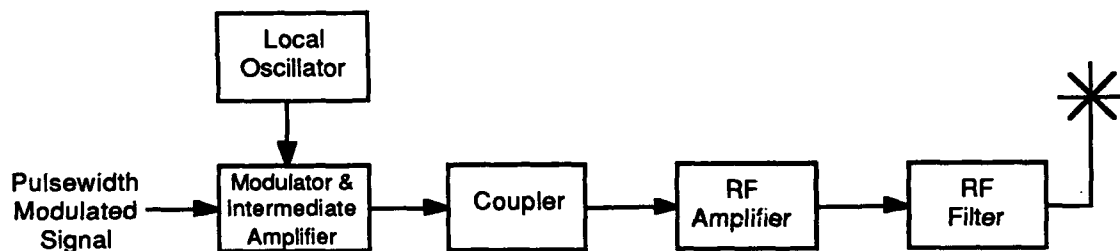


Figure 6: Transmitter Block Diagram

Transmitter system power was obtained from the telemetry power supply through a separate dual action switch on the telemetry package. The modulation process of the transmitted RF signal began with the serial pulse width modulated signal being fed from the encoder into the modulator and then combined with the crystal oscillator RF signal to produce a low-strength amplitude modulated (AM) signal. The AM signal was then amplified, filtered, and fed to the antenna impedance matching circuits for transmission over a 39.5-in omni-directional

whip antenna layed longitudinally along the starboard side of the F-16 model fuselage. The end result was a 600 milliwatt output signal transmitted at 27.195 MHz [Ref. 3:p. 6].

3. Hardware

The major components of the airborne subsystem were constructed as a single package on a 24-contact circuitboard and are shown in Figure 7.

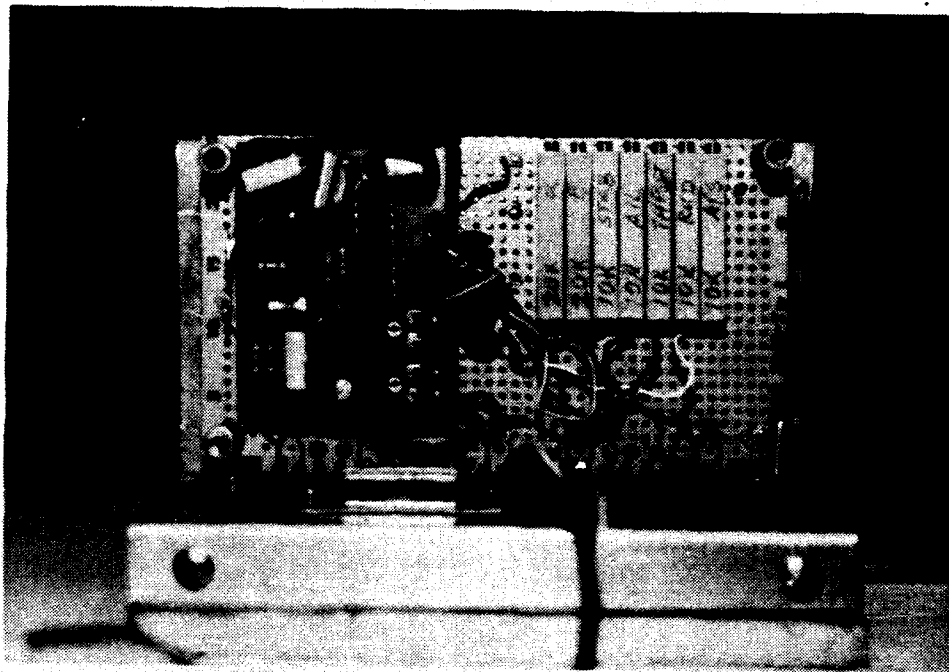


Figure 7: Airborne Subsystem

The package incorporated the encoder, transmitter, airspeed indicator, 26 pin input/output (I/O) connector and 15 pin test connector in a single unit covered by two removable pieces of particle board. The limited size of 32.5 in³ was compact enough to fit inside the model and provided adequate protection from damage during installation and removal. The package was secured in a transverse position inside the model's cockpit by a single rubber band on each of

the lower outboard sides. When this mounting technique was coupled with a 1/8 in foam pad across the bottom of the package there was adequate shock mounting to limit vibration transfer from the airframe to the package. Power from a 9.6 VDC, 500 mAh NiCad battery located in the starboard wing-root was supplied to the package through the input/output (I/O) connector via a two position toggle switch under the starboard leading edge extension. All wiring to and from the package utilized number-coded quick-release male/female fittings, with the exception of the 26-pin I/O connector which incorporated a dual screw arrangement to ensure proper connection and support of the larger plug. Wire number codes are depicted in Table IV and diagrams of the connector pins and the circuitboard gold contacts are provided in Figures 8, 9, and 10, respectively.

TABLE IV: AIRPLANE WIRE NUMBER CODES

Wire Number	Purpose
1	Airborne receiver channel 1 input- Aileron
2	Airborne receiver channel 2 input- Elevator
3	Airborne receiver channel 3 input- Throttle
4	Airborne receiver channel 4 input- Rudder
5	Airborne receiver channel 5 input- Gear
6	Airborne receiver channel 6 input- Beta
7	Airborne receiver channel 7 input- AOA
8	9.6 VDC, 500 mAh power from starboard battery to telemetry unit
9	4.8 VDC, 1200 mAh power from port battery to R/C receiver

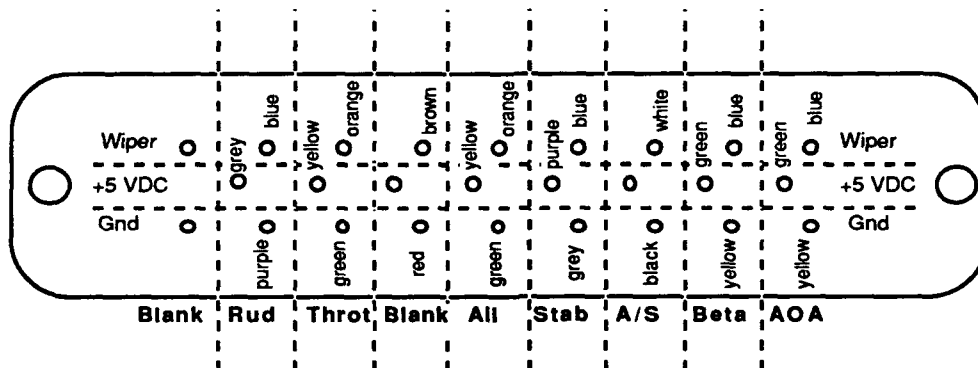


Figure 8: 26 Pin Input/Output Connector (male end)

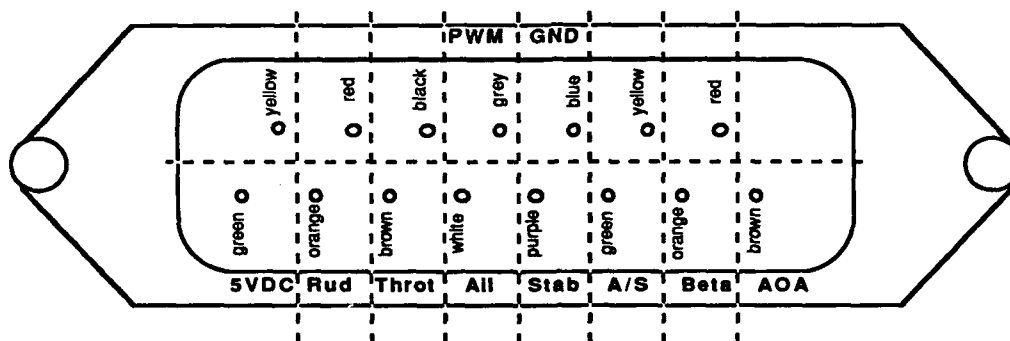


Figure 9: 15 Pin Test Connector (male end)

- | | |
|--|---|
| 1) ground | 12) 9.6V power for encoder and airspeed |
| 2) airspeed sensor input | 13) 5V reference from encoder |
| 3) 5V reference from encoder | 14) 5V reference from encoder |
| 4) 5V reference from encoder | 15) alpha pot wiper input |
| 5) a/s voltage output from indicator circuitry | 16) ground |
| 6) ground | 17) beta pot wiper input |
| 7) PWM signal from encoder | 18) stab pot wiper input |
| 8) 5V reference from encoder | 19) aileron pot wiper input |
| 9) 5V reference from encoder | 20) throttle pot wiper input |
| 10) 9.6V power for transmitter | 21) ground |
| 11) ground | 22) rudder pot wiper input |

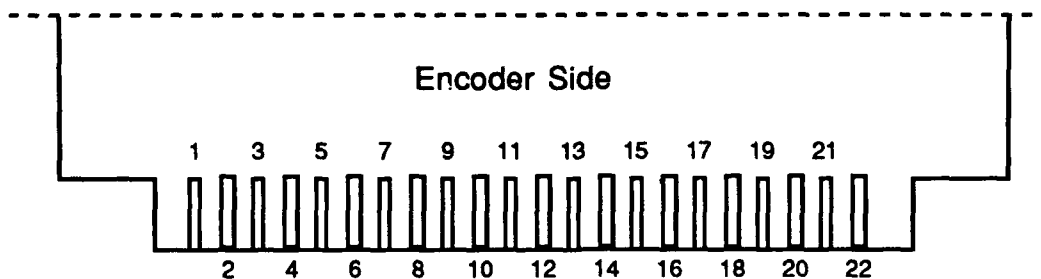


Figure 10: Circuitboard Pin Designations

C. GROUND-BASED SUBSYSTEM

The ground-based subsystem was comprised of a receiver unit, a demodulator unit, a display unit, and a recording unit, as shown in Figure 11.

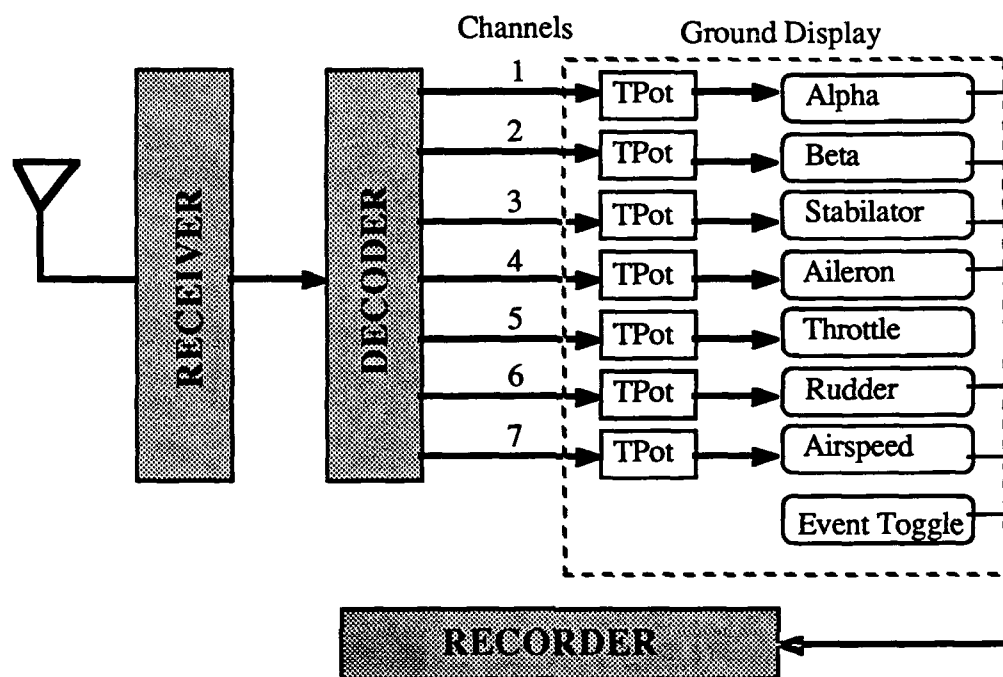


Figure 11: Ground-based Subsystem Block Diagram

The entire subsystem was powered by a single 9.6 VDC 800 mAh battery and assembled in a portable tool case measuring 13.5 X 6.0 X 18.5 in. The combined weight was 12.33 lbs.

1. Receiver Unit

The receiver unit was a commercially available ACE R/C Silver Seven super-heterodyned AM receiver located on the backside of the display panel. Its primary operating frequency was tuned at the factory, using the double tuned RF tuning circuit, to coincide with the transmitter frequency of 27.195 MHz. A block diagram of the receiver is presented in Figure 12.[Ref. 3:p. 1]

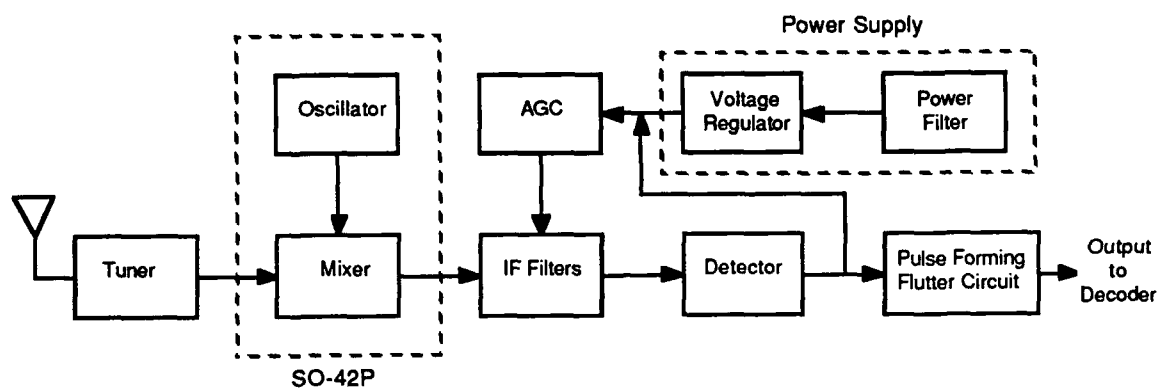


Figure 12: Receiver Block Diagram

The incoming signal was routed from the 39.5 in display mounted whip antenna through two parallel pass, inductively close coupled, filters for tuning. It was then forwarded to the mixer circuitry which utilized a Siemens SO-42P double balanced mixer to combine the encoded RF AM signal with the local oscillator signal of one half the nominal receiver frequency. The resulting heterodyned signals were then filtered to exclude all but a 455 KHz intermediate frequency (IF) and subsequently amplified. This process increased receiver selectivity from 100 to 5 KHz and rejected all signals more than 2.5 KHz from the center of the transmitted frequency before rectification and further amplification. Rectification to recover the modulation from the carrier was accomplished by the diode detector circuits. The rectified signal was amplified proportionally to the receiver input signal and also fed back to the automatic gain control (AGC) circuit in the filters to automatically bias the amplification process and provide an output which was not effected by signal strength. Coupling of the detected signal to the decoder was accomplished through the pulse forming flutter circuits. A simple RC filter circuit set to a cutoff frequency of 3 KHz

eliminated thermal noise from the detected signal while a diode/capacitor circuit eliminated flutter affects and coupled the detected signal to the decoder. Power for the receiver circuits was supplied by a +5V stabilized source on the integrator circuitboard.[Ref. 3;p. 1]

2. Demodulator Unit

The demodulator unit consisted of a decoder section and an integrator section mounted separately behind the ground unit display.

a. Decoder

The decoder unit was comprised of a programmable RC decoder circuit obtained from Ace R/C, and is shown in Figure 13[Ref. 3:p. 1].

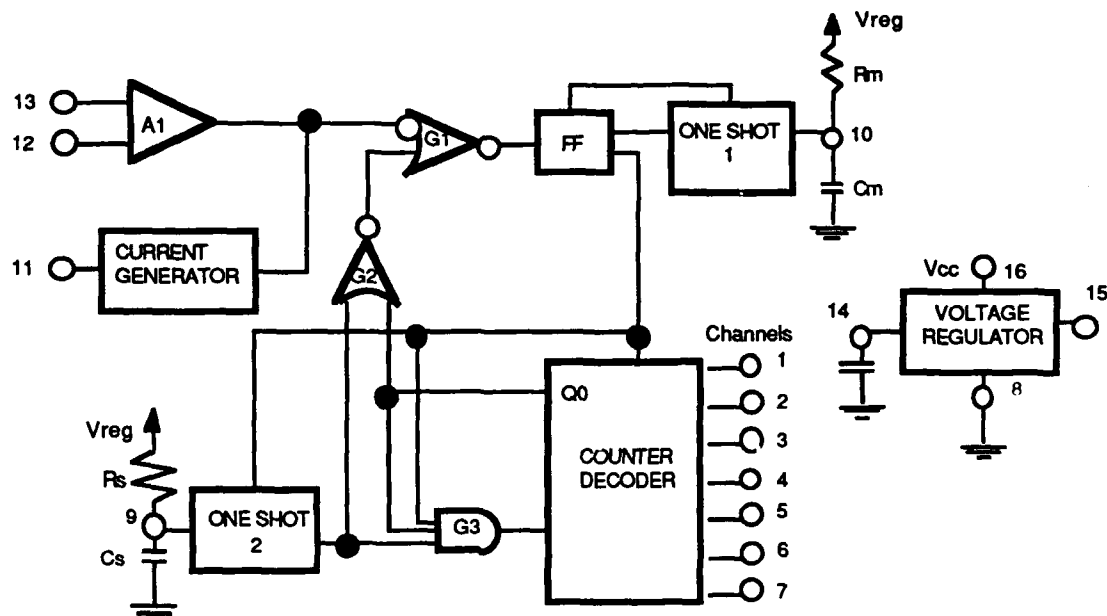


Figure 13: Decoder Circuit Diagram

An IC demultiplexer (NE5045), shown in Figure 14, provided the means of converting the serial pulse width modulated signal output from the receiver into seven, parallel pulsewidth modulated signals for input into the integrating circuitry.

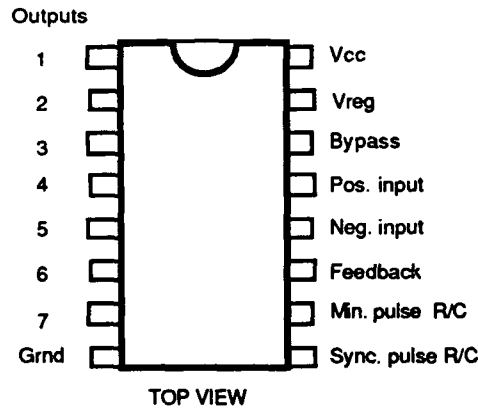


Figure 14: Decoder Circuitboard Pin Configuration

The high gain amplifier A1 had an input bias level less than 10 nA and allowed demodulation of signals with peak-to-peak voltage levels as low as 10 mV. The input to A1 incorporated a positive feedback loop from the current generator to create hysteresis in the input switching levels and prevent false triggering from noise or IF amplifier distortion. The threshold level at the input to A1 was set using a resistor divider network consisting of R₁, R₂, R₃, and R₄, shown in Figure 15. The threshold used for F-16 flight testing was calculated, using equation (3) and the values shown in Table V, to be preset at 433 mV.

$$V_{\text{threshold}} = V_r \left(\frac{1}{1 + R_1 / R_2} \right) \left(\frac{1}{1 + R_4 / R_3} \right) \quad (3)$$

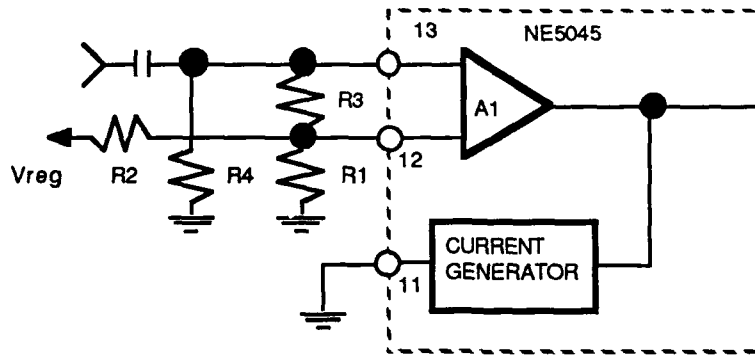


Figure 15: Resistor Divider Network

TABLE V: EXTERNAL CONFIGURATION OF NE5045 DECODER

Component	Value
R ₁	1.2 K Ω
R ₂	3.3 K Ω
R ₃	56 K Ω
R ₄	334.7 K Ω
R _m	47 K Ω
C _m	0.01 μ f
R _s	47 K Ω
C _s	0.1 μ f
V _{reg}	4.12 VDC

The amplified signal from A1 was gated by G1 which set the Flip-Flop (FF) and sent a pulse to the counter-decoder. The pulsewidth of this pulse thus set the minimum allowable input at 470 μ s using the relationship in equation (4).

$$T_m = R_m C_m \quad (4)$$

The FF also reset One Shot 2 which discharged C_s each time it was set. This discharge allowed C_s to begin recharging through R_s. The time constant for

recharging to occur was governed by equation (5) and was 3.995 ms for the F-16 flight tests.

$$T_s = 0.85 R_s C_s \quad (5)$$

Since the time constant was much larger than the time between input pulses, the output of One Shot 2 remained low until the last pulse of the time frame was received. The complex interaction of the decoder and associated circuits resulted in a parallel channel signal pattern with constant amplitude, variable pulsewidth signal trains, shown in Figure 16. Each channel was then output to a splitter panel for distribution to a corresponding integrating circuit. The output wiring from the receiver/decoder package was color coded as shown in Table VI.[Ref. 3:pp. 1-12]

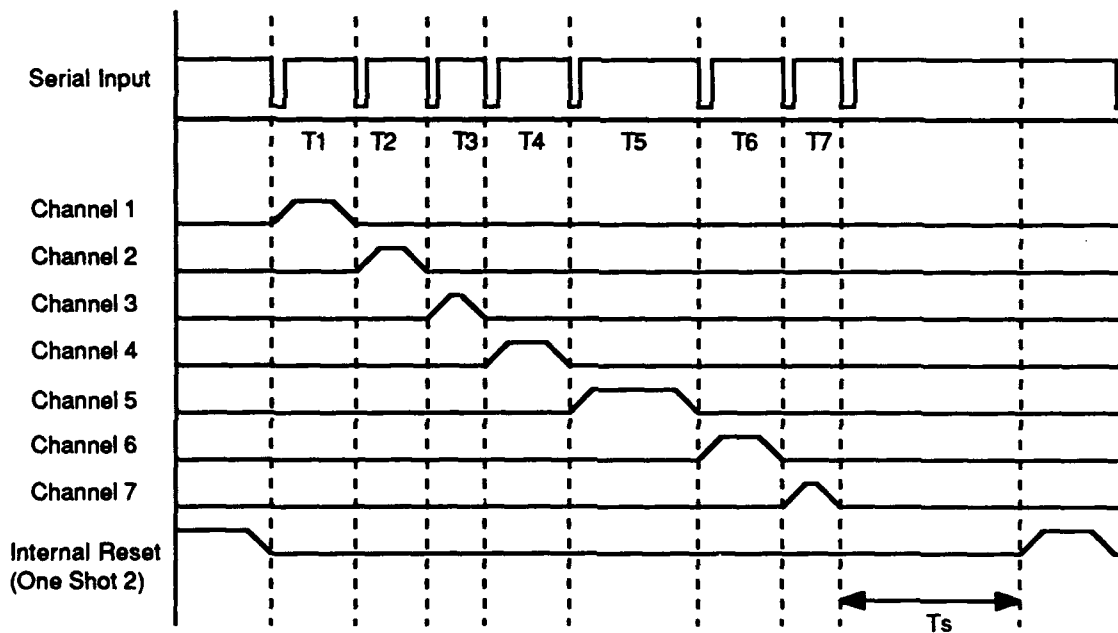


Figure 16: Decoder Timing Diagram

TABLE VI: DECODER OUTPUT COLOR CODING

Channel	Parameter	Color
1	AOA	Green
2	Beta	Blue
3	Stabilator	Brown
4	Aileron	Yellow
5	Throttle	Orange
6	Rudder	White
7	A/S	Green
n/a	VDC	Red
n/a	Ground	Black

b. Integrator Circuits

Outputs from the decoder were fed into a system of seven parallel integrators on two quad operational amplifier (op amp) chips (MC 3403P) to reproduce voltage fluctuations directly proportional to the aircraft voltage levels. The op amps and their associated RC networks were constructed on a single circuitboard, as shown in Appendix A, Figure 1, and were mounted behind the ground unit display panel. In addition to the amplifier circuits, the integrator circuitboard included a stabilized +5 VDC source responsible for reducing the +9.6 VDC battery power supply to power the receiver and providing a steady reference signal to the op amps. A block diagram of the integrator circuitry is presented in Figure 17.

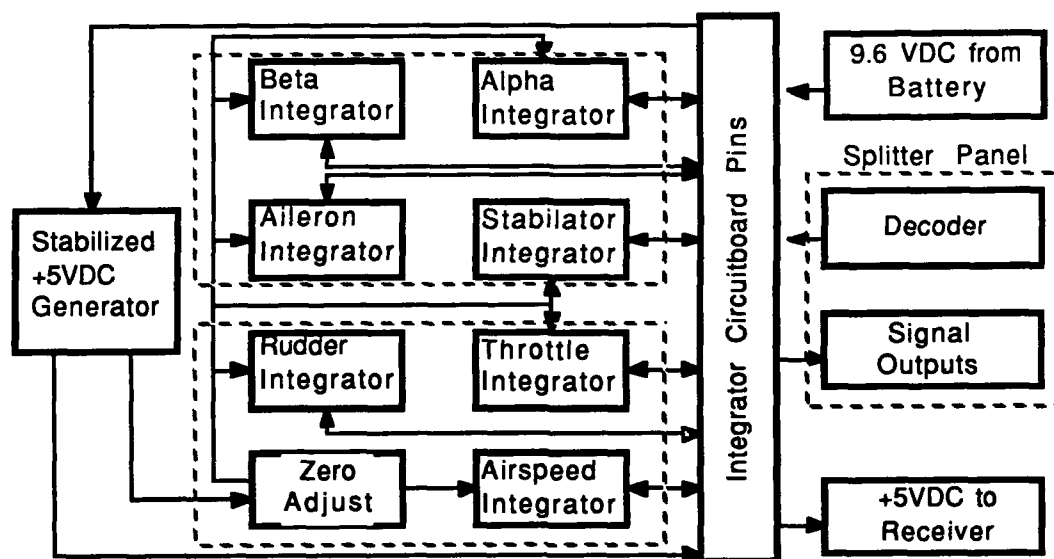


Figure 17: Integrator Circuitboard Block Diagram

The design of the integrator circuitry was driven by several considerations. Common off-the-shelf components had to be configured to provide the most linear voltage output possible while minimizing the integration time constant (τ) and providing stability. Additionally, op amp input impedances had to be matched with one another, while being kept below one tenth the value of the op amps internal impedance, to prevent biasing. The final design encompassed a number of features to meet the design objectives. To provide output stability, the circuit utilized a stable +5 VDC voltage source to drive all op amps at the same reference voltage and op amp gain was kept at a low value of 21. The RC feedback network associated with each op amp was responsible for setting this gain value, as well as smoothing the op amp output and eliminating any tendency for the output to oscillate. The gain of all seven op amps was the same and was

calculated using equation (6) with the resistance values of $R_c = 50 \text{ K}\Omega$ and $R_f = 1 \text{ M}\Omega$:

$$\text{Gain} = (R_f + R_c) / R_c \quad (6)$$

(note: other contributing resistances were one or more orders of magnitude lower and were excluded)

The system incorporated a Zero Adjust circuit utilizing a set of resistors and a single op amp to set a common reference voltage for the integrating op amps. This common reference voltage was required to offset the voltage output and maintain upper limits within the linear range of the integrator circuitry. Adjustments were made by manipulating the variable resistor (during calibration) until all integrator channel outputs were below +5 VDC (considered to be the upper limit of the linear range). The final output was approximately 3.5 VDC for a 1 ms pulsewidth data variation, given a 4 VDC pulse height. In order to reduce the impedance level of the reference voltage and prevent crosstalk between the integrating op amps, the reference signal was buffered by the Zero Adjust op amp with the gain set at one. The actual pulsewidth to voltage conversion occurred through the process of charging C_i through R_i . The value of the resistor R_i was chosen to be high in comparison to the decoder output and low in comparison to the integrator's internal resistance in order to provide proper impedance matching. This RC arrangement did, however, introduce the time constant (τ) which had to be minimized. The values of these RC components were optimized through an iterative process to be $R_i = 50 \text{ K}\Omega$ and $C_i = 1 \text{ Mf}$. The resulting time constant was determined to be 50 ms using equation (7).

$$\tau = R_i C_i \quad (7)$$

(note: other contributing resistances were one or more orders of magnitude lower and were excluded)

3. Data Recording/Display

Control position data from the integrator circuits corresponded to the voltage level outputs from the airplane's control potentiometers. However, the raw voltage data needed calibration and position error corrections, as well as conversion from voltage to angular control position, before they could be correlated for examination. Since accurate real-time manipulation was not feasible, rough calibration corrections were applied to the display indicators (necessary for establishing test conditions) and the data were recorded for more accurate postflight reduction.

a. Recorder

The recording unit was a TEAC HR-30E Portable Cassette Data Recorder. Its small size (150 X 95 X 45 mm), light weight (580 grams), and self-contained 9 VDC battery (12 hr duration) met the portability requirement and facilitated easy containment within the display unit. The seven channel analog voltage recording capability was directly compatible with the integrator output when the internal adjustment was set to the ± 10 VDC position. No further adjustments were required and inputs were fed to the recorder from the integrator circuits via a single splitter panel. The seven channels were wired to provide the correlations of channels to functions shown in Table VII.

TABLE VII: HR-30E RECORDER CHANNEL TO PARAMETER CORRELATION

Channel	Parameter
1	Event Marker
2	AOA
3	Beta
4	Stabilator
5	Aileron
6	Rudder
7	Airspeed

b. Display

The ground station display panel was designed to provide the flight test engineer with a visual indication of the airplane's seven monitored parameters and is shown in Figure 18.

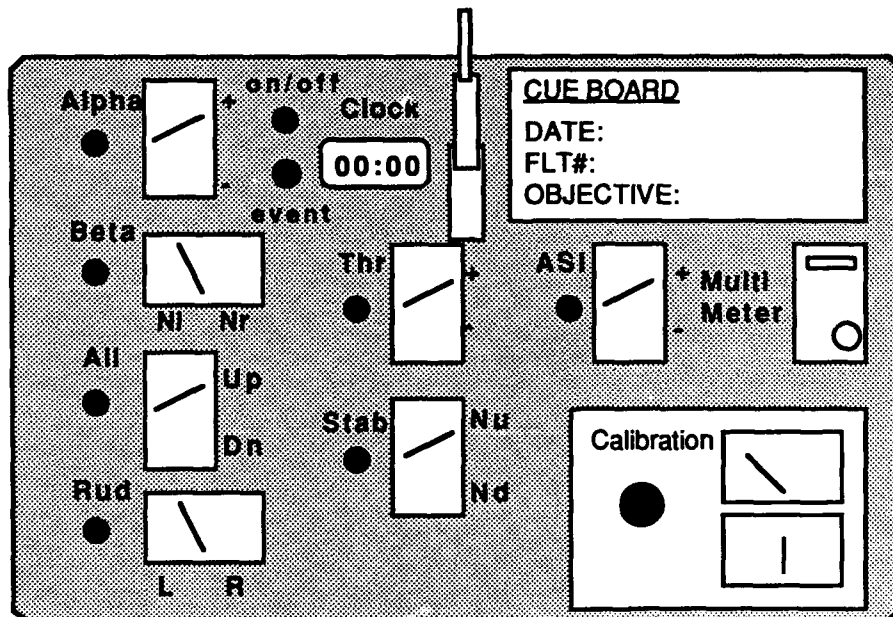


Figure 18: Ground Station Display Panel

The display panel was stowed in a horizontal position within the ground unit for protection and could be propped up at an angle 45 deg from the horizontal for easy viewing when the ground unit casing was open. A 39.5 in telescopic antenna located alongside the clock extended outward from the panel for improved reception. Each individual display was comprised of a potentiometer (pot) and analog multimeter placed in series with the output of each channel's integrator circuit. The pots served as calibration adjustments for their respective meters and enabled needle deflection to be optimized for each parameter. All wiring for the meters was attached to the back of the panel with the signals being fed from the splitter panel. A clock could have been installed as a synchronization device to facilitate comparisons of voltage recordings with video recordings of the display panel during post-flight analysis. The calibration portion of the display was not used for F-16 testing, but will provide the capability for field calibration of the encoder inputs when fully operational.

IV. F-16 MODEL INSTRUMENTATION

A. INSTRUMENTATION HARDWARE

1. Aileron and Stabilator

Control surface deflections for the aileron and stabilator were obtained using $5K\Omega$ potentiometers (pots) connected in parallel with the corresponding control actuating device, to the radio-controlled (R/C) servos. The physical linkage between each pot and actuating device was accomplished using a single rod attached at both ends with two 2D coupling nipples. Linkage throw was adjusted by lengthening or shortening the linkage arm to avoid over-center rotation of the pot and subsequent jamming of the control servo. Control position was obtained by monitoring the potentiometer output voltage as it deviated from the 5 VDC reference supplied by the telemetry (TM) package.

2. Rudder and Throttle

Accessibility and space limitations mandated instrumentation of rudder and throttle positions directly from the actuating servos in the cockpit section of the airplane. Servo-pot linkages which were similar in design to those used for aileron and stabilator were adjusted in a like manner.

3. Angle of Attack and Side-Slip

Angle of attack (AOA) and side-slip angle (beta) were determined using the wind vanes shown in Figure 19. Angle of attack was converted to a DC voltage using the system of rods, vanes, and gears depicted in Figure 20.



Figure 19: AOA and Beta Probe Arrangement

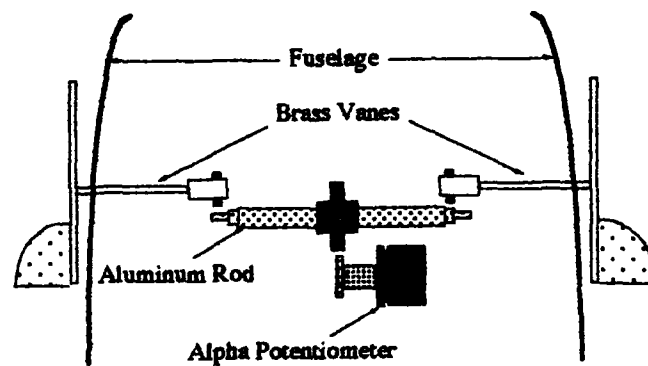


Figure 20: Alpha Vanes

The alpha measuring device was mounted in the forebody just ahead of the cockpit. A $20\text{ k}\Omega$ potentiometer was held in place by a set screw and spring combination which allowed longitudinal adjustment of the pot and subsequent adjustment of the gear mesh. A 1.3:1 gearing ratio provided 360 degrees of pot

rotation for 270 degrees of vane rotation and enabled finer AOA resolution by increasing the potentiometer's voltage bandwidth. Side-slip (beta) measurement also utilized a 20 k Ω pot which protruded vertically downward from the bottom of the alpha-beta framework. A single vane attached directly to the pot shaft was used for beta measurement in order to avoid interference from the airplane canopy. Both potentiometers were supplied a 5 VDC reference from the TM package.

4. Airspeed Indicator Circuitry

Airspeed was sensed using of a square-tipped, 1.75-in diameter, two-bladed propeller extending forward longitudinally on a 6-in aluminum extension rod positioned on top of the vertical stabilizer, as shown in Figure 21.

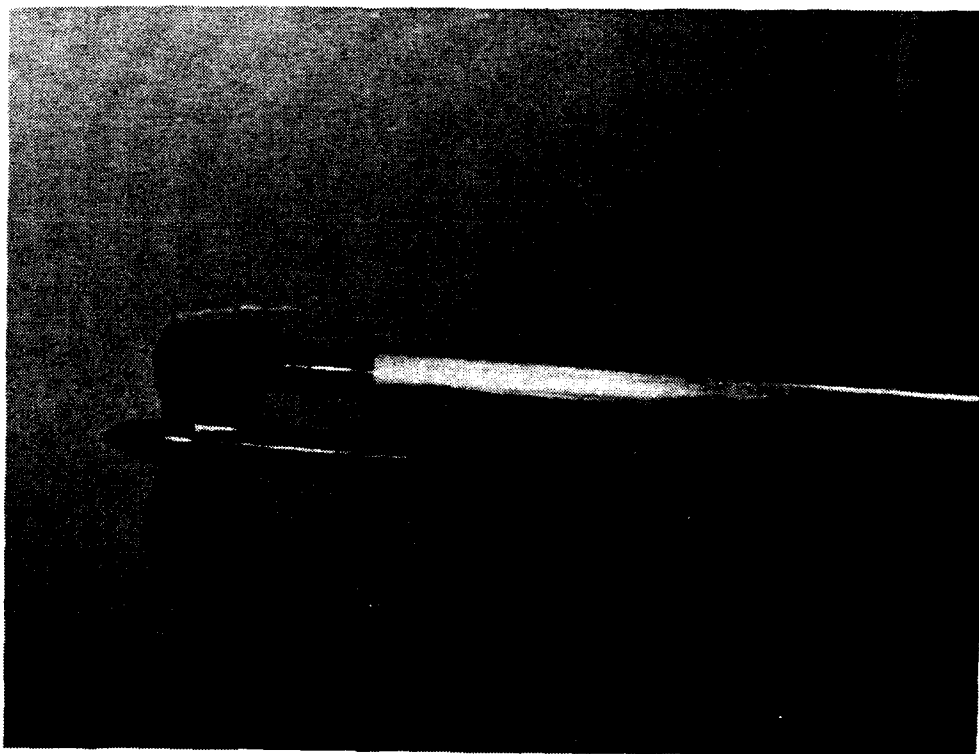


Figure 21: Airspeed Sensor

The propeller was rated for operation from 19 to 184 mph, which corresponded with potential project airplane capabilities of from 30 to 130 mph. Each propeller blade trailing edge contained a blocking device which would momentarily (twice per revolution) cover a Cadmium-Sulfide (CdS) photo sensor, located on the boom behind the propeller. A reference 9 VDC signal fed to the photo sensor received a spike from the CdS photo sensor, during each blade passage, prior to signal processing being done. The modified reference signal was continuously monitored by an electronic circuit, depicted in Figure 4, which converted the spiked DC signal to a smooth DC signal directly proportional to propeller rpm and of variable amplitude (0-5 VDC).

Frequency-to-voltage conversion by the circuit was accomplished using an LM2917 chip and supporting components, shown in Figure 22.

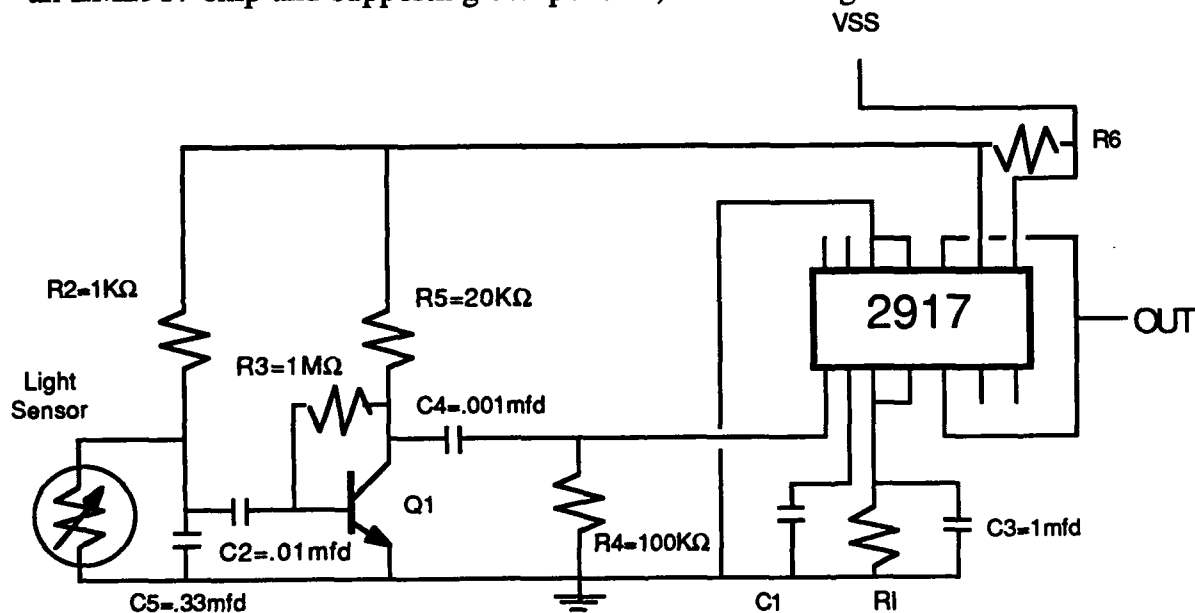


Figure 22: Airspeed Sensor Circuit Diagram

A high-gain amplifier modified the nonsinusoidal sensor signal to the required sinusoidal input for the LM2917 amplifier. Following amplification, the signal

was sent through an RC combination charge pump comprised of R1 and C1. The RC combination established a charging current proportional to the amplifier input frequency and then discharged a pulse-modulated voltage to the buffer amplifier portion of the circuit. Capacitor C3 then integrated the pulses to provide a DC voltage level directly proportional to the input frequency. Resistor and capacitor values of 300 k Ω and 0.06 μ f were chosen for R1 and C1, respectively, to obtain a 4.75 VDC output for the maximum expected frequency of 300 Hz, produced at 135 mph.

B. CALIBRATION

1. Purpose

Temperature, humidity, structural configuration, and equipment geographical location had a significant impact on the electrical signals produced and recorded by the telemetry system. Day-to-day variations were as high as ± 0.1 VDC in the laboratory environment. As a result, laboratory and field calibration were deemed necessary.

2. Methodology

a. Laboratory

(1) **Pulsewidth.** Laboratory calibration was concerned with ensuring individual pulsewidth integrity of each of the seven serial pulses input to the airborne TM transmitter. Pulse train observation from the airborne TM unit was accomplished using the 15 pin test connector and the Tektronix 2245A oscilloscope, with oscilloscope controls configured to the baseline settings shown in Appendix B, Table IV. Test probes from the oscilloscope were connected to the test connector using the patch panel associated with the 15 pin test connector and the ground circuit was completed by attaching the patch panel grounding

wire to the airborne TM package. Each of the seven instrumented devices (alpha, beta, stabilator, aileron, throttle, rudder, and airspeed) was individually moved through its anticipated full range of motion while being observed on the oscilloscope screen. Airplane control surfaces and throttle position were moved using the PCM 10247 radio control transmitter outfitted with a transmit module corresponding to the airplane's receiver code. Alpha and beta vanes were rotated manually; the airspeed sensor was excited with a General Radio Company Strobotac 1531-A stroboscope.

Optimum pulsewidth for the individual pulses within the serial pulse train input to the TM transmitter was $1.0 \text{ ms} \pm 0.5 \text{ ms}$. By adjusting a trimming potentiometer placed in series between each instrumentation potentiometer (airspeed channel did not have pots) and the TM modulator, the voltage input to the modulator was raised or lowered to expand or contract the displayed pulsewidth. Adjustment of the voltage in this manner ensured the upper and lower limits of 0.5 and 1.5 ms were not exceeded. Furthermore, observations of the pulsewidths enabled the fine tuning of each channel's potentiometer position by displaying discontinuities when control deflections were swept through a potentiometer null. Rotation of the pot to a new position which relocated the null to a clock-position outside of the control deflection could be accomplished manually.

Flight control and wind vane positions were referenced to a line along the longitudinal axis. An SP1 Protracto Level II electronic level was placed on top of the F-16 fuselage with the forward edge of the level coinciding with the forward edge of the fuselage upper surface access slot, aft of the cockpit. Lateral positioning was accomplished by allowing the

level's concave lower surface to rest uniformly on the cambered upper section of the fuselage. The level's zero adjust was then depressed to establish the reference datum. With the airplane remaining in the same position it was when the reference datum was established, the control and vane position reference marks/lines were drawn on the airplane by positioning the electronic level at the control/vane rotation point and marking a zero angle. A protractor was then positioned with its origin superimposed over the center of the control/vane axis of rotation and with its zero angle corresponding with the zero reference mark from the electronic level. Angle reference could then be drawn using the protractor as a reference. Alpha and beta vane calibration points were highlighted with tick marks at -45, 0, and +45 deg. Aileron and rudder calibration lines were drawn on the fuselage so that the control's inboard upper and lower surfaces aligned with the calibration lines when the control's camber line was deflected to -10, 0, and +10 degrees. The stabilator was calibrated in a similar manner to the aileron and rudder; however, space limitations mandated using angles of -5, 0, and +5 degrees.

(2) **Airspeed.** Laboratory calibration of the airspeed sensor was conducted in two parts. First, sensor voltage output to the modulator was correlated with airspeed. The NPS Aerolab Low Speed Wind Tunnel located in the basement of Halligan Hall was used to accomplish this initial correlation calibration. The airspeed sensor was affixed to a five-inch high, 90-degree angled probe and inserted into the wind tunnel test section with zero beta. Sensor leads were then routed along the probe to the outside of the tunnel and to the F-16 model. Voltage readings were obtained using a Fluke 8842A Digital Multimeter connected to the airspeed lead of the 15 pin test connector

(connected to the TM package) when the TM transmitter was on. A flashlight was used to illuminate the sensor and all florescent lighting in the test area was secured to avoid 400 Hz interference in the data. The wind tunnel was operated in third gear from 20 to 110 mph in approximate 5 mph intervals during tests over a three-day time period. Tunnel velocity was obtained using standard manometer conversion factors. Water manometer readings from the tunnel pressure differential ports were converted to dynamic pressure (q) using equation (8).

$$q = a(-0.026749 + b\Delta P) \quad (8)$$

where: "a" was the conversion factor for cm of water to lbs/ft² (2.047)

"b" was the tunnel calibration factor (1.1149) [Ref. 4: p. 21]

The perfect gas equation (9) was manipulated and inserted in the dynamic pressure equations (8) and (10) to yield the velocity equation (11).

$$P = \rho RT \quad (9)$$

$$q = \frac{1}{2} \rho U^2 \quad (10)$$

$$U = \sqrt{\frac{2(2.282\Delta P)RT}{P}} \quad (11)$$

where: V had units of mph

ΔP had units of lbf/ft²

R was gas constant for air (1716 ft-lbf/slugs -°R)

P was the local barometric pressure (lb/ft²)

The resulting data, presented in Appendix B, Figures I-III, were used to produce the calibration curve shown in Figure 23. Electromagnetic interference (EMI)

between the TM transmitter and airspeed circuitry was noticed in the output voltage trace on the oscilloscope when the antenna impedance was not optimized. Shielding the transmitter inside a grounded metal casing provided a 50% reduction in the interference, but did not eliminate the effects. Reflected power was thought to be responsible for the EMI and after several antenna adjustment iterations the EMI appeared to be minimized. The resulting antenna was an inductor-loaded, 39.5 inch, 75 Ω whip extending from the transmitter board and grounded to the transmitter shield casing.

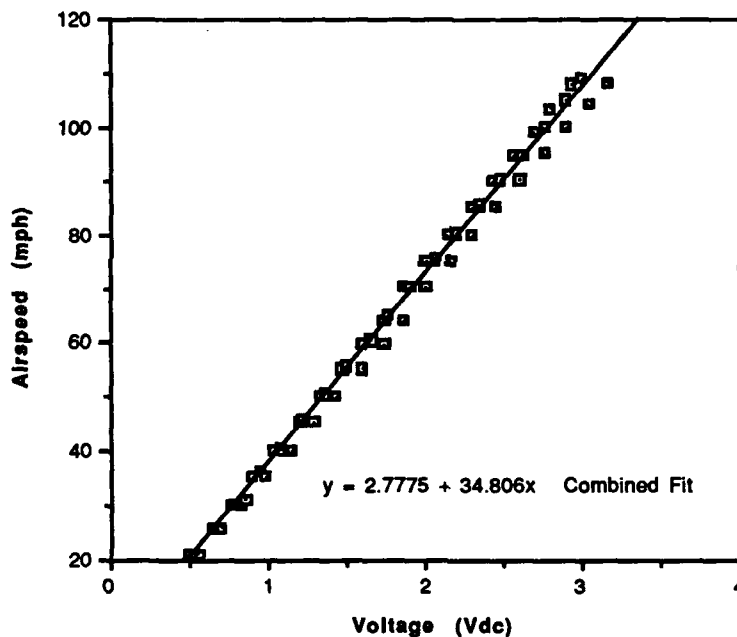


Figure 23: Airspeed Calibration Curve

The second laboratory calibration phase for the airspeed sensor was concerned with replicating sensor system output voltages without wind-flow over the propeller. With the lab lighting secured, the airspeed sensor reinstalled in the F-

16 tail sting, and the TM system test connections reconfigured as in the previous airspeed calibration section, a General Radio Company Strobotac 1531-A stroboscope was positioned directly ahead of the sensor. Stroboscope frequency was varied until the desired transmitter output voltage was achieved. Recordings were made of the ground-based systems receiver's output voltage simulating 50, 75, and 110 mph, using 1.35, 2.0, and 3.0 VDC respectively, for later correlation with flight test data, since replication of these test conditions was not practical in the field.

(3) Data Recorder and Player. Calibration of the HR-30E Cassette Data Recorder with the MR-30 Cassette Data Recorder began with a preliminary operational check of the MR-30. The operational check followed the manufacture's recommended procedures [Ref. 5:pp 25-28]. A calibration tape was then made using the HR-30E. To create the calibration tape, a BK Precision DC Power Supply Model 1630 was hard-wired to the HR-30E input channels via a splitter panel. Two voltage levels (0 and 10 VDC) were then recorded for two minutes apiece. The HR-30E was configured for normal data recording with all changeover switches set to "data" and all internal level select switches set to ± 10 VDC peak-to-peak.

(note: these settings allowed the full use of the instrumentation potentiometer outputs and enabled the 9.6 VDC event marker to be visible)

After the calibration tape was made, it was replayed through the MR-30. Tape operation in the MR-30 was similar to that of standard cassette players in use in the home; however, special function switches were more numerous. Tape replay required all slide switches on the Mode Selector Panel to be set to "data" or

"off". In addition, tape speed had to be set to correspond with the HR-30E record speed of 4.8 cm/sec. On the monitor panel, the switches were set to "DC" or "out" and one end of a BNC connector cable was connected to the "monitor" position. The other end of the BNC connector cable was attached to the Fluke 8842A Digital Multimeter for more precise output readings. While the tape played through the zero voltage recording, each channel was calibrated to zero. Sequentially depressing the "CH Selector" button permitted each channel to be viewed and adjusted independently, with the active channel designated by illumination of the individual "MONI" light emitting diode (LED). The "REP - ZERO" set screw for the displayed channel was then rotated as required to give a 0 VDC indication on the multimeter. After the zero point was set, the output level was adjusted by recycling through the seven channels using the 10 VDC recording and adjusting the "REP-LEVEL" set screw to attain a 10 VDC reading on the multimeter. Following the calibration procedure, channel 1 was selected for event marker monitoring of flight test data. All other settings were left undisturbed.

b. Preflight / Postflight

Immediately before and after each flight, a calibration procedure was performed for the control surfaces and the wind vanes to allow postflight correlation of angular deflections with recorded voltage levels. Surfaces and vanes were moved to their calibration positions in a three-step procedure. The sequence of deflections is depicted in Table VIII.

Table VIII: CALIBRATION SEQUENCE

Control	1st Position	2nd Position	3rd Position
AOA	down	0	up
Beta	right	0	left
Stabilator	down	0	up
Aileron	down	0	up
Rudder	left	0	right

Deflections were ordered to provide positive deflections first. Positive was defined by a deflection which created a negative moment for control surfaces, a nose-up attitude for AOA, or wind from the starboard side for beta. Voltage outputs from the ground-based TM unit were recorded on the HR-30 recorder while the controls and vanes were simultaneously held in position at each of the three desired positions. The event marker was momentarily toggled to place a designator signal on the recording and indicate that data for the desired configuration had been obtained.

V. DATA REDUCTION

A. GENERAL

Analog voltage recordings made by the HR-30E recorder were continuous DC voltage outputs from the seven channels of the ground-based integrator circuitry. Interpretation of these recorded voltages required their conversion back to the angular or linear deflections upon which they were based. A computer-aided conversion process was established for this purpose. The process consisted of 1) converting the voltages from analog to digital form using a MetraByte A-to-D conversion card; 2) sampling and storing the digital data with software installed on an IBM PC; and 3) software correlation of recorded voltage levels with actual displacements using calibration files.

B. EQUIPMENT

1. Computer

An IBM Personal Computer AT (PC/AT) was used for data reduction. The computer hardware was configured with a Seagate 20 megabyte internal hard-drive, low density 5.25 inch internal floppy drive, high density 5.25 inch internal floppy drive, standard IBM keyboard, and a 13 inch monochrome monitor. The disk operating system (DOS) software utilized was IBM DOS version 2.01; however, an auxiliary software management system tool was employed with DOS in order to make the computer more "user friendly". The management tool used was "Sideview Two". Sideview Two was configured as an autoexec batch file to immediately provide a menu driven decision path for the computer operator. It provided options for executing Lotus, Wordperfect, and

Labtech Notebook software programs, returning to DOS, or formatting low and high density floppy disks. A detailed description of "Sideview Two" can be found in the Sideview Two Operators Manual [Ref. 6] A table of the most commonly used DOS commands can be found in Appendix B, Table V.

2. MetraByte Card

a. General

A MetraByte converter card, model DASH-16F (PC-6102) was installed in the fifth expansion slot of the PC/AT. The DASH-16F was a multi-function high speed analog/digital data acquisition and signal analysis card offering 8 differential or 16 single ended analog input channels. It incorporated a 12 bit successive approximation converter for improved throughput rate and offered three modes of data transfer: programmed via the control processor unit (CPU), interrupt via the CPU, and direct memory access (DMA). Optional features included an assembly language source listing, a 1 MHz timer, and a graphics package for data manipulation /correlation.

b. Configuration

Basic operation of the DASH-16F was controlled by manual switches on the card, shown in Appendix A, Figure 2. Eight differential channel operation was selected with the "CHAN CNFG" since the recorder, player, and computer were operated using different ground loops. Operation in this manner prevented the differences in voltage caused by multiple ground sources from ending up appearing in series with the input signal, thus reducing noise in the data. Unipolar 0-2 VDC range settings were selected to correspond with MR-30 outputs by setting the five position dipswitches marked A, B, C, D, and USER to ON, OFF, ON, OFF, and OFF, respectively. The DMA slide switch was set to

level 1 to provide DMA to the internal hard-drive, and following manufacturer's recommendations, base address was set at 300 by setting base address switches 9, 8, 7, 6, 5, and 4 to OFF, OFF, ON, ON, ON, and ON respectively.

Data input to the DASH-16F was accomplished via a 37 pin "D" type male connector attached to the card and protruding from the back of the computer. A system of coaxial cables and ribbon wire provided the data-link from the MR-30 to the 37 pin input connector.

C. DATA MANIPULATION/PROCESSING

1. Data Recorder/Player

a. Background

Continuous A-to-D data conversion was not possible because of limited storage space on the hard-drive and the slower read-write rates associated with high sampling rates. In order to identify specific data points to be converted and stored, discrete voltage jumps were placed on channel 1 of the recording using the event marker toggle on the front face of the ground-based TM unit. Identification of the designated points required continuous monitoring of the MR-30 output on channel 1.

b. Configuration

Data reduction settings on the MR-30 were similar to those settings used for calibration. Primary deviations from the previous settings involved the Meter & Monitor Panel. With the SOURCE/OUT slide switch set to OUT and the CH SELECTOR button depressed a sufficient number of times to illuminate the channel 1 MONI LED, tape play was initiated. Attention was then focused on the output level indicators. Data extraction was manually initiated through the

computer when the MR-30 analog meter needle achieved a deflection of 100% and the LED meter went off the scale.

c. Noise

Calibration of the MR-30 and HR-30E data recorders revealed two sources of noise in the recorded data. A test signal of +1.0000 VDC was produced with a BK Precision DC Power Supply model 1630, then recorded on the HR-30E and replayed through the MR-30. Data conversion was performed by the MetraByte card through the IBM PC/AT at a sampling rate of 5 kHz over 0.02 seconds. The resulting plot is shown in Figure 24. Signal-to-noise (S/N) ratios of the MR-30 and HR-30E allowed a variation of 2.5% of full scale. This equated to a maximum ± 50 mV for the 0-2 VDC range of the MR-30 (clearly evident in the waveform shown in Figure 24). Sinusoidal variations in the data were the result of carrier waveform interference from the MR-30. The specified MR-30 carrier bandwidth of 270 Hz/VDC equated to 540 Hz of carrier distortion for a 0-2 VDC range. The observed distortion was approximately 500 Hz, as shown in Figure 24. Since the noise appeared to be random in nature and the carrier distortion frequency was consistent, a decision was made to average the data points over a 0.25 sec interval. The result was a voltage of 1.0000 \pm .0005 VDC.

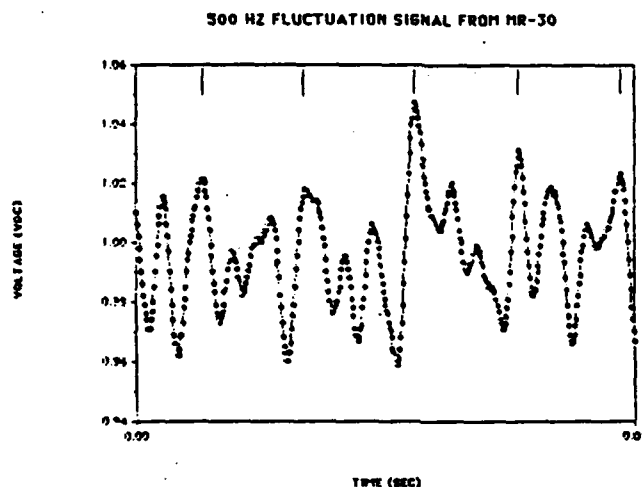


Figure 24: 500 Hz Fluctuation of Random Noise in MR-30 Data Output

2. Programs

a. Labtech Notebook Software

Labtech Notebook version 4 provided the interface between the operator and the instrumentation. It was used to control computer operation as well as MetraByte card input routing during data extraction/conversion. NOTEBOOK was completely menu driven through a system of multiply-tiered heading bar displays, and as such required only superficial knowledge of the IBM computer DOS. Specific features available through NOTEBOOK included DOS command access, real-time display of sampled data, variable sample rates, data manipulation, time-code correlation, compatibility with the MetraByte card, automated or manual triggering, and graphics. NOTEBOOK was stored on the internal hard-drive in the NOTEBOOK sub-directory. A detailed description of Labtech Notebook can be found in the Labtech Notebook Operators Manual [Ref. 7].

(1) Configuration. Installation of the Labtech Notebook software onto the PC/AT hard-drive was accomplished following procedures outlined in the Operators Manual. Basic operational modes for NOTEBOOK were determined by reconfiguring default settings on the applicable menus. Reconfiguration was accomplished by scrolling through the selected menu using the arrow keys, and then once positioned over the insertion point, by typing over the existing information or depressing "F1" and subsequently scrolling through a secondary options window with the "F10" or "F9" keys. Acceptance of a new setting was achieved by depressing the carriage return key. Exiting the current menu was accomplished by depressing the ESC key. Applicable menus were dictated by the data acquisition speed and the interface device chosen upon initial configuration setup of the operating mode.

NOTEBOOK's interactive capability was enabled by sequentially selecting INSTALL and HARDWARE menus, followed by the DASH-16F device. Additionally, keyboard initiation of data samples was enabled by selecting OPTIONS from the INSTALL menu, then selecting YES from the secondary options window.

Manual sequential selection of SETUP, CHANNELS, and HIGHSPEED menus enabled direct analog-to-digital conversion rates of greater than 20 Hz and eliminated all data display and analysis menu options. Selection of the high-speed mode was dictated by the noise generated in the MR-30 tape player and the 50 ms time constant limitation from the integration circuitry in the ground-based TM. A 5000 Hz sample rate for 0.25 sec was determined necessary for data conversion. This high rate provided sampling at five times the Nyquist recommended rate of 1000 Hz and ensured the 500 Hz noise could be

averaged out. The 0.25 sec duration was chosen to cover a period of five integration time constants to eliminate premature sampling of decoded voltage levels. The CHANNELS menu was also used to select the number of channels (7), the type of each channel (analog), and any scale factor desired (1).

(2) Data Storage Files. Data storage format was determined by selecting SETUP and FILE menus. In the high-speed mode the number of data files was limited to one and channel number sequence entries were automatically set from 1 to 7. Data storage mode was chosen to be ASCII Real in order to present a readable form for the operator. Data file names were changed for each converted data point to avoid over-writing the previous point and to correspond with input files for the REDUCE program. Required file name formats are shown in Table IX.

TABLE IX: NOTEBOOK STORAGE FILE NAMES

Filename	Usage
CAL1A.DAT	Used in conjunction with the first preflight calibration point
CAL2A.DAT	Used in conjunction with the second preflight calibration point
CAL3A.DAT	Used in conjunction with the third preflight calibration point
CAL1B.DAT	Used in conjunction with the first post-flight calibration point
CAL2B.DAT	Used in conjunction with the second post-flight calibration point
CAL3B.DAT	Used in conjunction with the third post-flight calibration point
XXXX.XXX	Any standard filename.extension can be used for flight data points

Each time the REDUCE program scanned a data file for processing, six lines of alphanumerics were ignored before data were read into the program. This

process mandated channel name, channel units and the maximum number of header lines (4) be included in each storage file setup using the FILES menu.

(3) **SAVE Menu.** Once the setup was complete all SETUP menu options were stored using a single name under the SAVE menu. TEST.DAT was the name used for the F-16 data reduction; however, any standard filename.extension could have been used for the configuration to be saved. Although it was not required during the course of this thesis, the SAVE SETUP feature would have prevented time consuming reentering of setup information if the system had been used for several different reduction applications. The last setup entered prior to shut-down, whether stored or not stored, was always the default setup upon re-application of power to the system.

b. REDUCE Program

(1) **General.** The REDUCE program was designed to be the link between the voltage signals and angular/linear displacements. It was written in ASCII format and then compiled using FORTRAN 77 version 3.2 for the IBM PC. The primary focus of the program was establishing calibration files or interpolating/extrapolating flight test data from previously generated calibration files. REDUCE was a data reduction program written specifically for averaging and correlating seven channel output files generated from high-speed NOTEBOOK operation, and thus relied on the existence of previously saved files delineated in Table I. The program was nested within the NOTEBOOK sub-directory on the PC/AT hard-drive to ensure access to the NOTEBOOK data files. A copy of REDUCE is presented as Appendix C.

(2) **Calibration File Construction.** Construction of a calibration file was possible using pre-calibration, post-calibration or both pre-calibration

and post-calibration data. REDUCE prompted the operator to respond with yes or no answers, 1 or 0 respectively, to determine what combination of files were to be used. If pre and post-calibration files were utilized, each file was reduced independently and then the two were averaged together to form a new file, CAL.DAT. Calibration integrity was checked by comparing each original file to the new file before program continuation. Exceeding the maximum allowable deviation of 15% resulted in a "pre- and post- cal values differ too much" message delivered to the operator via the screen and program termination. Precise control and wind vane positioning was required during the calibration procedure in order to ensure accurate data and avoid this error message.

F-16A calibration required some manual intervention in addition to the above procedure. Since airspeed calibration in the field was not possible, the CAL.DAT file previously generated had to be edited to include laboratory calibration data for airspeed. Reduction of the laboratory calibration run data was performed as described above; however, the resulting file was visually inspected and airspeed voltage calibration values were noted by hand. Following the field calibration data run, the cal.dat file was edited using DOS EDLIN commands to incorporate laboratory calibration values for airspeed.

REDUCE allowed flexibility in the deflection settings used during field calibration. The sequence described in Table VIII required equal magnitude deflections in the positive and negative directions, but the magnitudes were not specified. REDUCE accounted for variations in calibration deflections by allowing operator input of the deflection values through screen prompts and keyboard inputs. Alpha, beta, stabilator, aileron, and rudder inputs were variable; however, airspeed calibration values of 50, 75, and 110 mph were built

into the program because field calibration of airspeed was not feasible. The CAL.DAT file used for F.16A flight testing is presented in Appendix B, Table VI.

(3) Flight Test Data Correlation. Flight test data averaging and correlation was also accomplished using REDUCE, after the CAL.DAT file had been created. Screen prompted responses were used to indicate a flight test data reduction run had been initiated and to activate the interpolation/extrapolation portion of the program. Additional prompts then asked for the filename.ext of the flight test data file previously stored using NOTEBOOK. Ground-based TM voltage outputs and airplane control/vane displacements had demonstrated a linear relationship throughout all laboratory testing. REDUCE therefore incorporated a linear interpolation/extrapolation routine which, after averaging the converted voltages, used the CAL.DAT file as a basis for converting the flight test voltages to angular/linear displacements.

VI. FLIGHT TESTING

A. GENERAL

The ultimate goal of this thesis was to demonstrate successful integration of all supporting elements of a telemetry system. Completion of this thesis was therefore keyed to obtaining usable F-16A control/vane position data through flight test maneuvers. Specific objectives included the evaluation of: ground unit displays, useful ranges, data quality, and overall integration of the entire TM system and its supporting equipment.

B. PREPARATION

1. Checklists

Efforts to enhance coordination and safety throughout the flight test phase required the establishment of, and strict adherence to, several checklists. A heavy reliance on dc battery power for the airplane R/C receiver, airplane R/C transmitter, airborne TM unit, ground TM unit, data recorder, and video cameras mandated battery packs be fully charged prior to each flight test day. The Battery Charging Checklist, included in Appendix D, was implemented in order to ensure all required batteries were indeed recharged. Additionally, since the voltages and durations of the batteries varied significantly, the Battery Charging Checklist also served as a guide for setting the individual charger rates at one tenth the mAh rating for each battery.

Supporting equipment for the F-16A combined with the many segments of the TM system to create a large inventory to be transported to the flight test site. Inadvertent absence of any one of several key pieces of equipment could

have delayed testing or even cancelled it. The Equipment Checklist, shown Appendix D, was generated to eliminate the possibility of delays.

2. Weight and Balance

Weight and balance was calculated in the lab to document the F-16A flight configuration and satisfy safety-of-flight concerns. Manufacturer's recommendations for center-of-gravity (CG) location were specified as, "...3.5 to 3.75 inches ahead of the engine former [Ref. 8:p. 21]." Since the engine former was an internal veneer plywood frame to which the engine fan and duct were mounted, it was difficult to use as a reference. The wing root leading edge was therefore chosen as an alternate reference datum and the CG tolerances were transcribed as 6 to 6.25 inches aft of the wing root leading edge. Weight measurements were individually taken for each of the F-16A landing gear mounts while the airplane remained in a level configuration. Four-by-four inch blocks were used to elevate the airplane to accommodate an Arlyn Electronic Scale. The scale was positioned beneath each wheel and a reading taken for both empty and fully fueled airplane configurations. Elementary moment arm calculations were performed using the geometry shown in Figure 25 and CG range, shown in Table X, was determined. The slightly forward CG location was acceptable for flight.

C. FLIGHT MANEUVERS

1. General

Flight testing of the F-16A was accomplished at Fritzsche Army Airfield, Fort Ord, CA. Scheduling of the field was only permitted on weekends and was accomplished through base operations three working days in advance. The length of the runway, isolation from other airborne traffic, and large open

areas were necessary to ensure the safe operation of the airplane and the integrity of test results. Since the airplane was being flown by an experienced R/C modeler who was unfamiliar with ducted-fan R/C models, extra flights were scheduled into the flight test sequence to familiarize the pilot with the F-16A scale model.

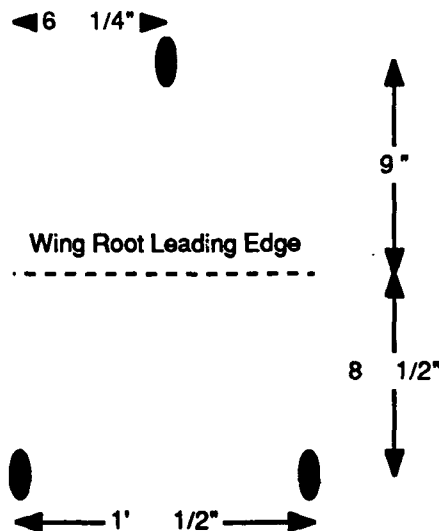


Figure 25: F-16A Landing Gear Positions Relative to the Wing Root Leading Edge

TABLE X: F-16A GROSS WEIGHTS AND CG LOCATIONS

Fuel	Gross Weight	CG Location
Empty	14.00 lb	5.48 in aft
Full	15.53 lb	5.53 in aft

2. Procedures

The specific test sequence for the flight is delineated in the Flight Test Procedures Checklist shown in Appendix D. Special emphasis was placed on maintaining an accurate record of the R/C receiver battery usage in order to prevent expiration of the battery life and loss of airplane control. Fuel usage was also closely monitored to avoid engine fuel starvation. These items, as well as the required flight test information were, recorded on the Flight Test Data Sheets shown in Appendix D.

Steady heading side-slips were flown to evaluate the lateral-directional character of the airplane and the accuracy of the TM system. With the throttle set at full (due to throttle problems) the airplane was flown upwind at 50 feet above ground level and allowed to drift with the wind to establish a level flight baseline. On each successive pass the amount of rudder deflection was increased $1/4$ of the full rudder deflection range and airplane heading was maintained constant using ailerons. Once full rudder had been attained, the procedure was repeated in the opposite direction.

3. Results

Ground testing was conducted to check for the possibility of electromagnetic interference (EMI) and to determine the useful range of the TM prior to flight. With both the TM transmitter and receiver activated, a two-man team carried the airplane away from the receiver with the airplane lateral axis pointing in the direction of the TM receiver. Separation distance was then steadily increased until the system was out of range. TM receiver display needles provided a good indication of when the system was in or out of range and were used to determine the useful range. Anytime the transmitter was out of range the

needles would return to a fixed position. In this manner, the useful range of the TM was determined to exceed the 300-foot planned flight envelope for the airplane. Additionally, there did not appear to be any EMI problems between the TM and R/C systems.

TM ground unit monitoring was continued during the pilot familiarization flight. The ground unit position was maintained on the south side of the runway while the airplane flew a standard right-hand traffic pattern around runway 29. General reception was good with signal nulls noted each time the airplane pointed directly toward or away from the TM ground unit. Stable indications were present throughout the upwind portion of the pattern and control deflection indications were consistent with pilot actions. TM data were therefore considered to be reliable and the decision was made to continue with flight testing. Other data gathered during the first flight included: an initial fuel consumption rate which allowed a maximum flight time capability of 40 minutes; adequate control of the airplane with the forward CG location; and control deflections determined to be adequate for the airplane flight envelope.

Steady heading side-slip data are presented in Figure 26 and Table XI. The data were consistent with stable airplanes and show that the F-16A airplane was well trimmed. The negative signs for all aileron deflections were a result of the calibration zero position not coinciding with the natural trim position of the aileron. High airspeeds were the result of full-throttle operation. Data scatter is believed to have resulted from pushing the pilots' capabilities and attempting to fly the airplane in a steady maneuver before sufficient proficiency was established.

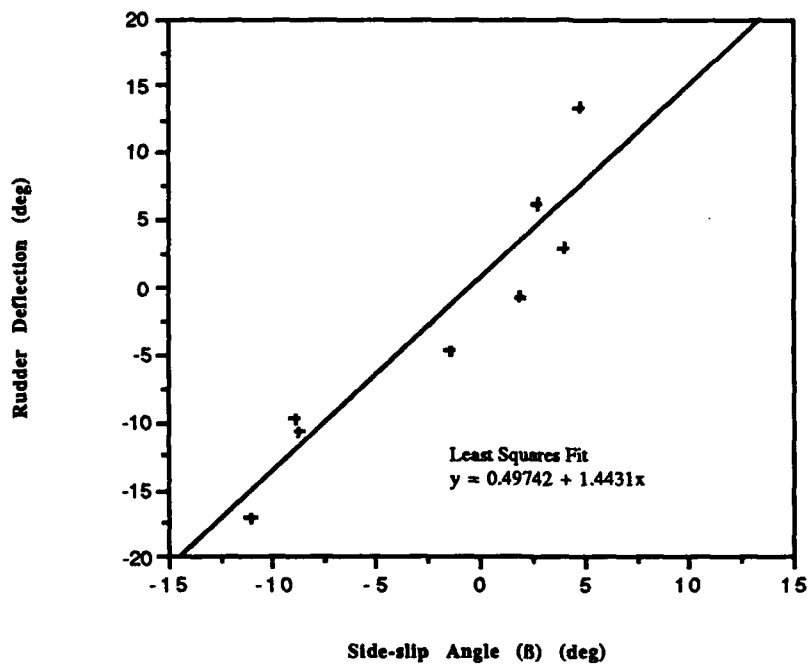


Figure 26: Steady Heading Side-Slip Data Plot

TABLE XI: STEADY HEADING SIDE-SLIP DATA

AOA (deg)	BETA (deg)	STAB (deg)	AIL (deg)	RUD (deg)	A/S (deg)
2.35	-8.94	-6.54	-1.05	-9.65	106.54
1.71	-8.70	-5.46	-1.02	-10.73	106.48
2.65	-11.02	-4.37	-0.23	-17.08	106.52
-1.16	1.92	-4.46	-2.51	-0.69	106.60
-1.90	3.97	-4.19	-2.78	2.92	106.58
-0.48	2.69	-4.50	-3.41	6.19	106.41
-3.25	4.67	-4.13	-3.18	13.45	106.53
-3.21	-1.42	-4.18	-2.91	-4.70	106.47

VII. CONCLUSIONS AND RECOMMENDATIONS

A. GENERAL

Within the scope of this test, the CHOW-1G telemetry system and supporting data reduction equipment were found to be satisfactory for RPV parameter monitoring. The complex interaction of the overall system was manageable but required a thorough understanding of each component's operation and limitations. Further flight testing is recommended using a testbed airplane with known performance data. This would provide accurate comparison information and allow a more in-depth quantitative analysis of the system accuracy to be performed.

B. AIRPLANE

The F-16A airplane provided an adequate testbed for initial telemetry experimentation. CG tolerances were flexible enough and thrust available was great enough to facilitate introduction of the TM without seriously degrading airplane performance. Operation of the airplane did, however, reveal several areas of concern which are applicable to all RPV testing.

- The high level of noise in the vicinity of the airplane with the engine running made voice communication impractical. Hand signals between the pilot and plane handler should be worked out prior to engine operation.
- The photo sensor and airspeed circuitry vulnerability to EMI coupled with inconvenient calibration requirements to increase the complexity and reduce confidence in the airspeed system. A small low power dc pressure transducer

with lower EMI vulnerability and field calibration capability would greatly ease the data reduction workload.

- Airplane flight maneuvers, which need to be performed to collect useful data, require a high degree of pilot technique to be done correctly. This technique can only be gained through pilot proficiency and practice. A method of providing pilot access to the flight test vehicles without jeopardizing thesis research should be examined more closely to ensure the required level of proficiency is maintained.

C. TELEMETRY

Successful operation of the CHOW-1G Telemetry System has shown that a compact, low-cost, low-weight system has direct application in RPV flight testing. Vibration and "g" loading did not seem to affect TM operation and reliability was good. The ground displays worked to provide good qualitative indications concerning the status of the data link and how individual TM channels were performing. Specific recommendations regarding the telemetry system include:

- Precise tuning of the TM transmitter and receiver combination should be accomplished. The lower power output from the Silver-Seven components proved adequate for the limited flight radius of R/C models; however, tuning should improve the overall signal-to-noise capability of the system.

- Adopt of system for direct entry of pulsewidth modulated data from the TM receiver to the computer. A small lap-top computer configured with a specialized computer board would eliminated three sources of data noise by removing the recorders and A-to-D converter from the data reduction loop.

- Examine the possibility of expanding the number of channels. This would allow incorporating accelerometers into the instrumentation package without the loss of control position or wind vane information.

- Incorporate gearing mechanisms as links between instrumentation potentiometers and control and vane displacements instead of rod links. The rod-link system posed a safety hazard with the possibility of having a potentiometer lock-up in an over-center position if rod throw was too great. Gears would eliminate this safety problem and gearing ratios could then be chosen to optimize potentiometer throw.

REFERENCES

1. Salmons, J. D., *Developmental Flight Testing of a Half-Scale Unmanned Air Vehicle*, Master's Thesis, Naval Postgraduate School, Monterey, California, September 1990.
2. Cleaver, C. M., *Development of an Unmanned Air Research Vehicle for Supermaneuverability Studies*, Master's Thesis, Naval Postgraduate School, Monterey, California, March 1990.
3. *Silver Seven Assembly and Operation Manua*, Ace R/C, Inc, Higginsville, Missouri, 1983.
4. Yuan, C. C., *The Effects of Forebody Strakes on Asymmetric Vortices on a Vertically Launched Missile*, Master's Thesis, Naval Postgraduate School, Monterey, California, September 1990.
5. *MR-30 Portable Cassette Data Recorder Instruction Manual*, TEAC Corporation of America, 1986.
6. *Sideview Two Users Manual*, 2nd ed., Keller Software, 1988.
7. *Labtech Notebook Instruction Manual*, 4th ed., Laboratory Technologies Corporation, 1988.
8. *F-16 Owner's Manual*, Byron Originals Inc., 1988.

APPENDIX A: FIGURES

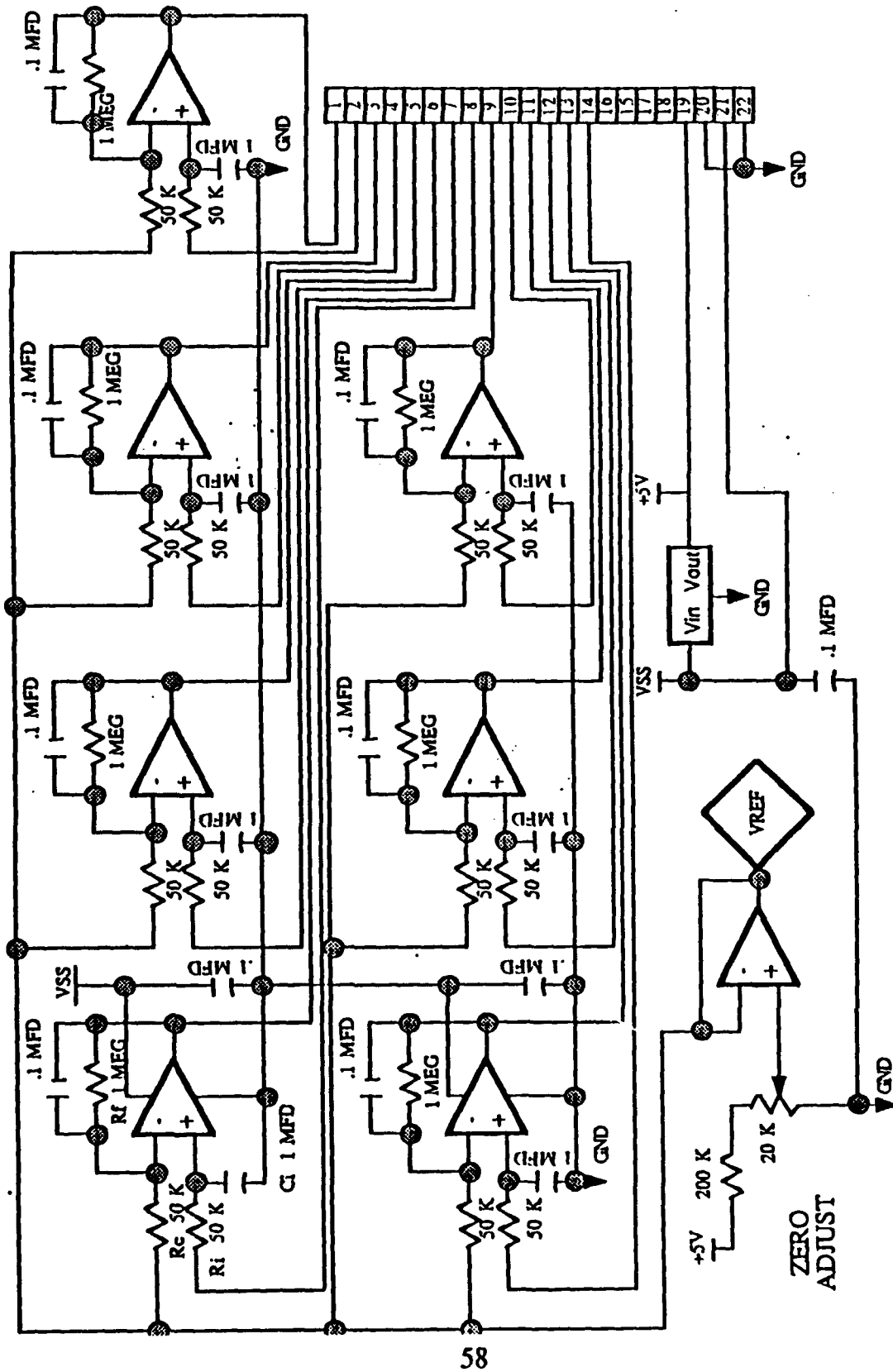


Figure 1: Integrator Circuit Diagram

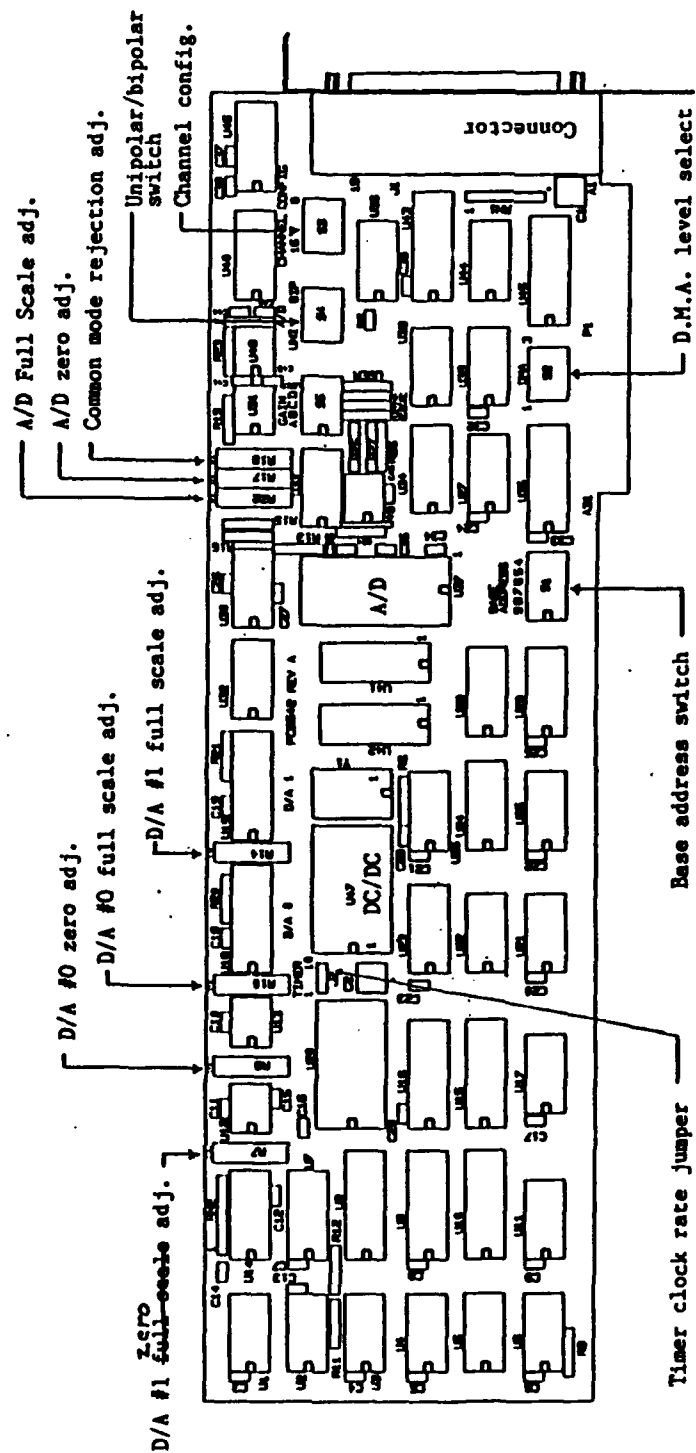


Figure 2: A/D Converter Board

APPENDIX B: TABLES

TABLE I: AIRSPEED CALIBRATION RUN 1 DATA

Run#1		zero a/s= 0.71		
Temp: 62deg				
F				
Press: 29.96		Date: 5 Jun		
Delta p	Airspeed (mph)	Airspeed (fps)	Voltage (Vdc)	RPM
1.050	31.340	46.07	0.850	
1.430	36.350	53.44	0.950	
1.790	40.530	59.58	1.070	
2.350	46.290	68.05	1.220	
2.800	50.450	74.16	1.350	
3.410	55.580	81.71	1.500	
4.050	60.510	88.94	1.650	
4.650	64.780	95.23	1.760	
5.500	70.400	103.48	1.900	
6.300	75.300	110.69	2.060	
7.150	80.180	117.87	2.190	
8.100	85.310	125.4	2.340	
9.050	90.140	132.51	2.470	
10.000	94.730	139.25	2.610	
11.100	99.780	146.68	2.760	
12.300	105.010	154.37	2.900	
13.250	108.980	160.19	3.000	

TABLE II: AIRSPEED CALIBRATION RUN 2 DATA

Run#4				
Temp:62-64 deg F				
Press: 30.01			Date: 7Jun	
Delta p	Airspeed (mph)	Airspeed (fps)	Voltage (Vdc)	RPM
0.500	21.152	31.093	0.500	
0.750	25.906	38.081	0.640	
1.000	29.913	43.973	0.750	
1.400	35.394	52.029	0.900	
1.800	40.133	58.996	1.040	
2.300	45.366	66.688	1.200	
2.800	50.055	73.580	1.330	
3.400	55.158	81.082	1.470	
4.000	59.827	87.945	1.600	
4.600	64.157	94.311	1.730	
5.500	70.153	103.125	1.860	
6.300	75.082	110.371	2.000	
7.100	79.707	117.169	2.140	
8.100	85.135	125.149	2.290	
9.000	89.740	131.918	2.430	
10.000	94.595	139.054	2.560	
11.000	99.212	145.841	2.680	
12.000	103.623	152.326	2.800	
13.000	107.854	158.546	2.920	

TABLE III: AIRSPEED CALIBRATION RUN 3 DATA

Run#3		Zero: 0.05		
Temp: 63deg F				
Press: 29.87		Date: 8Jun		
Delta p	Airspeed (mph)	Airspeed (fps)	Voltage (Vdc)	RPM
0.500	21.181	31.137	0.560	
0.750	25.942	38.135	0.700	
1.000	29.955	44.034	0.830	
1.400	35.443	52.102	0.980	
1.800	40.189	59.078	1.140	
2.300	45.429	66.781	1.290	
2.800	50.125	73.683	1.430	
3.400	55.235	81.195	1.590	
4.000	59.910	88.068	1.730	
4.600	64.247	94.443	1.860	
5.500	70.251	103.269	2.000	
6.300	75.187	110.525	2.150	
7.100	79.818	117.332	2.300	
8.100	85.254	125.323	2.450	
9.100	90.363	132.834	2.600	
10.100	95.199	139.942	2.750	
11.100	99.801	146.707	2.900	
12.100	104.199	153.173	3.040	
13.100	108.419	159.377	3.160	

TABLE IV: OSCILLOSCOPE BASELINE SETTINGS

Control	Setting
Intensity	mid-range
Focus	as desired
Input	channel 1
Volts/Div	2V/division
Sec/Div	0.5 ms
Coupling	DC
Position Controls	as desired
Trigger	default

TABLE V: IBM DOS COMMANDS

Command	Purpose
DEL or ERASE filename.ext	to eliminate named file
DIR C:	lists the directory of C (hard) drive
CD\	changes directory to default
CD\XXX.XX	changes directory to specific sub-directory
CTL C	to stop a listing
CTL S	to temporarily halt a listing (to resume hit any key)
*	replaces unknown text
COPY *.DAT B:	duplicates on B drive, all files with DAT extension in current directory
COPY RAW.DAT c:\F16	duplicates the file RAW.DAT from current dir to the F16 sub-directory on the C drive
MD F16	creates a sub-directory called F16
RD F16	removes sub-directory F16
TYPE FILENAME.EXT	prints the desired file on the screen
EDLIN C:FILENAME.EXT	commands the line edit program to open the named file
I	for inserting in EDLIN
D	for deleting in EDLIN
#, # L	lists specific lines in EDLIN
Q	for quitting EDLIN
C:"cr" CD\SV "cr" SV"cr" or AUTOEXEC.BAT	two ways to execute Sideview program
REN FILENAME.EXT_ FILENAME.EXT	renames the first file with second name

TABLE VI: CAL.DAT DATA FILE FOR F-16A FLIGHT TEST

.0390	.0125	.4252	.0154	.0135	.0300
.1827	.0841	.2632	.2776	.1551	.8330
.3714	.1912	.0372	.6078	.3725	2.000
+45	+45	+10	+10	+20	50
0	0	0	0	0	0
-45	-45	-10	-10	-20	110

APPENDIX C: REDUCE PROGRAM LISTING

```

$storage:2
$debug
c*****c
c
c   Input data files for calibration should be:
c
c       CAL1A.DAT for the first point;
c       CAL2A.DAT for the second (zero) point; and
c       CAL3A.DAT for the third point.
c
c   If a second calibration is carried out after the flight test,
c   then these files should be CAL1B.DAT, etc.
c
c   The files will be averaged together for the final output
c   calibration file, CAL.DAT.
c
c   The final output file with the results of the flight test
c   is OUTPUT.DAT, where there are 6 columns with the number
c   of rows equal to the number of data points.
c
c*****c
c
c   dimension alpha(8),beta(8),dele(8),dela(8),delr(8),as(8)
c   dimension iaoa(3),ibeta(3),istab(3),iail(3),irud(3),ias(3)
c   dimension data(6),cal(6,6),output(6),xdata(6,20)
c   character*14 fn1,fn2,fn3,fn4,fn5,fn6,fn7,fn8,fn9
c   character*1 dummy
c   integer flag,flag2,flag3
c   data fn2/'c:calla.dat'/
c   data fn3/'c:cal2a.dat'/
c   data fn4/'c:cal3a.dat'/
c   data fn5/'c:callb.dat'/
c   data fn6/'c:cal2b.dat'/
c   data fn7/'c:cal3b.dat'/
c   data fn8/'c:cal.dat'/
c   data fn9/'c:output.dat'/
c
c   m = 1
c   write(*,'(a\)' ) ' Is this run for calibration? [0/1]: '
c   read(*,*) flag
c   if (flag.eq.1) go to 100
c   write(*,'(a\)' ) ' This run is for reducing data. '
c   write(*,'(a\)' ) '
500 write(*,'(a\)' ) ' Enter file (D:FILENAME.EXT) to read data: '
c   read(*,'(a14)' ) fn1
c   open(1,file=fn1,status='old')
c   open(8,file=fn8,status='old')
c   open(9,file=fn9,status='new')
c   go to 101
100 continue
c   write(*,'(a\)' ) ' Was there a post-flight calibration? [0/1]: '
c   read(*,*) flag2
c   open(2,file=fn2,status='old')
c   open(3,file=fn3,status='old')

```



```

        open(4,file=fn4,status='old')
        open(8,file=fn8,status='new')
        if (flag2.eq.0) go to 101
        open(5,file=fn5,status='old')
        open(6,file=fn6,status='old')
        open(7,file=fn7,status='old')
c
    101 continue
        write(*,'(a\)'')' How many points to average?: '
        read(*,*) npt
        init = 1
        ifin = 1
        if (flag.eq.0) go to 102
        init = 2
        ifin = 4
        if (flag2.eq.1) ifin = 7
c ***** big loop *****
    102 do 110 j = init,ifin
c***** read 6 lines of alphabetics
        do 10 i = 1,6
            10 read(j,'(a10)')dummy
c***** initialize for summation
            aoa = 0.0
            side = 0.0
            stab = 0.0
            ailrn = 0.0
            rud = 0.0
            aspd = 0.0
c
            do 20 i=1,npt
                read(j,900)event,xaoa,xside,xstab,xailrn,xrud,xaspd
                aoa = aoa + xaoa
                side = side + xside
                stab = stab + xstab
                ailrn = ailrn + xailrn
                rud = rud + xrud
                aspd = aspd + xaspd
            20 continue
                alpha(j) = aoa/npt
                beta(j) = side/npt
                dele(j) = stab/npt
                dela(j) = ailrn/npt
                delr(j) = rud/npt
                as(j) = aspd/npt
c
    110 continue
c
        if (flag.eq.0) go to 130
c ***** average calibration values
        if (flag2.eq.0) go to 125
        do 120 j = 2,4
            jj = j+3
            alpha(j) = (alpha(j) + alpha(jj))*0.5
            beta(j) = (beta(j) + beta(jj))*0.5
            dele(j) = (dele(j) + dele(jj))*0.5

```

```

    dela(j) = (dela(j) + dela(jj))*0.5
    delr(j) = (delr(j) + delr(jj))*0.5
    as(j) = (as(j) + as(jj))*0.5
c***** check on calibration
    ckal = (alpha(jj)-alpha(j))/alpha(j)
    ckbe = (beta(jj)-beta(j))/beta(j)
    ckde = (dele(jj)-dele(j))/dele(j)
    ckda = (dela(jj)-dela(j))/dela(j)
    ckdr = (delr(jj)-delr(j))/delr(j)
    ckas = (as(jj)-as(j))/as(j)
c***** 15% difference in pre- and post- cal values assumed ok
    err = 0.15
    if (abs(ckal).gt.err) go to 111
    if (abs(ckbe).gt.err) go to 111
    if (abs(ckde).gt.err) go to 111
    if (abs(ckda).gt.err) go to 111
    if (abs(ckdr).gt.err) go to 111
    if (abs(ckas).lt.err) go to 115
111 write(*,'(a)') ' Pre- and post- cal values differ more than 15% '
    go to 999
115 continue
120 continue
125 continue
    do 140 j=2,4
    write(8,900) alpha(j),beta(j),dele(j),dela(j),delr(j),as(j)
140 continue
    write(*,'(a)') ' All inputs will be positive numbers, assuming '
    write(*,'(a)') ' the same deflections + and -. Assumptions are: '
    write(*,'(a)') '
    write(*,'(a)') ' Alpha: positive [nose up, vane down] first; '
    write(*,'(a)') ' Beta: positive [nose left, vane right] first; '
    write(*,'(a)') ' Stab: positive [t.e. down] first; '
    write(*,'(a)') ' Ailrn: right ailrn positive [t.e. down] first; '
    write(*,'(a)') ' Rudder: positive [t.e. left] first; '
    write(*,'(a)') ' Airspd: '
    write(*,'(a)') '
    write(*,'(a)') ' Input all deflections in whole degrees. '
    write(*,'(a)') '
    write(*,'(a\')') ' Angle of attack? : '
    read(*,*) iaoa(1)
    write(*,'(a\')') ' Beta? : '
    read(*,*) ibeta(1)
    write(*,'(a\')') ' Stab? : '
    read(*,*) istab(1)
    write(*,'(a\')') ' Aileron? : '
    read(*,*) iail(1)
    write(*,'(a\')') ' Rudder? : '
    read(*,*) irud(1)
    write(*,'(a\')') ' Airspeeds (low, med, hi) mph? : '
    read(*,*) ias(1),ias(2),ias(3)
c
    iaoa(2) = 0
    ibeta(2) = 0
    istab(2) = 0
    iail(2) = 0

```

```

        irud(2) = 0
c
        iaoa(3) = -1*iaoa(1)
        ibeta(3) = -1*ibeta(1)
        istab(3) = -1*istab(1)
        iail(3) = -1*iail(1)
        irud(3) = -1*irud(1)
c
        do 150 i=1,3
        alphac = iaoa(i)
        betac = ibeta(i)
        stabc = istab(i)
        ailrnc = iail(i)
        rudc = irud(i)
        asc = ias(i)
        write(8,900) alphac,betac,stabc,ailrnc,rudc,asc
150 continue
        go to 999
130 continue
c ***** redefine as test data values
        data(1) = alpha(1)
        data(2) = beta(1)
        data(3) = dele(1)
        data(4) = dela(1)
        data(5) = delr(1)
        data(6) = as(1)
c ***** read calibration values
c ***** alpha is cal(1,n), beta is cal(2,n), etc.
        do 160 i = 1,6
160 read(8,900) (cal(j,i), j = 1,6)
        do 300 j = 1,6
        output(j) = 999.
c
        k = 0
c ***** check to see if datum equals cal value
        if (data(j).eq.cal(j,1)) output(j) = cal(j,4)
        if (data(j).eq.cal(j,2)) output(j) = cal(j,5)
        if (data(j).eq.cal(j,3)) output(j) = cal(j,6)
        if (output(j).ne.999.) go to 300
c ***** check to see between what values: 1 and 2, or 2 and 3?
        if (data(j).gt.cal(j,1).and.data(j).lt.cal(j,2)
@.or.data(j).lt.cal(j,1).and.data(j).gt.cal(j,2)) k = 1
        if (data(j).gt.cal(j,2).and.data(j).lt.cal(j,3)
@.or.data(j).lt.cal(j,2).and.data(j).gt.cal(j,3)) k = 2
        if (k.ne.0) go to 350
        write(*,'(a\)' )' Datum is out of bounds of cal for sensor: '
        write(*,*) j
        write(*,'(a)' )' alpha = 1, beta = 2, elevator = 3 '
        write(*,'(a)' )' aileron = 4, rudder = 5, airspeed = 6 '
        write(*,'(a)' )' Datum will be extrapolated. '
c
c ***** check for direction of extrapolation
        if (data(j).gt.cal(j,1).and.data(j).gt.cal(j,2)
@.or.data(j).lt.cal(j,1).and.data(j).lt.cal(j,2)) k = 1
        if (data(j).gt.cal(j,2).and.data(j).gt.cal(j,3)

```

```

      @.or.data(j).lt.cal(j,2).and.data(j).lt.cal(j,3)) k = 2
c
c ***** interpolation or extrapolation
350 output(j) = cal(j,k+4)-((cal(j,k+1)-data(j))/(cal(j,k+1)-
    @cal(j,k)))*(cal(j,k+4)-cal(j,k+3))
300 continue
    do 310 j = 1,6
    xdata(j,m) = output(j)
310 continue
    write(*,'(a\\') ' More data points? [0/1]: '
    read(*,*) flag3
    if (flag3.eq.0) go to 510
    m = m + 1
    go to 500
510 do 520 i = 1,m
520 write(9,900) (xdata(j,i), j = 1,6)
c
999 close (1)
    close (2)
    close (3)
    close (4)
    close (5)
    close (6)
    close (7)
    close (8)
    close (9)
900 format(7f9.4)
    stop
    end

```

APPENDIX D: CHECKLISTS

BATTERY CHARGING CHECKLIST

- ☐ RC Receiver - 4.8 Vdc 1200 mAh
- ☐ RC Transmitter - 9.6Vdc 500 mAh
- ☐ RC Extra Xmit Battery - 9.6 Vdc 500 mAh
- ☐ TM Transmitter - 9.6 Vdc 500 mAh
- ☐ TM Receiver - 9.6 Vdc 800 mAh
- ☐ Video Battery

EQUIPMENT CHECKLIST

- ___ Airplane
 - ___ Canopy and Screws
 - ___ Alpha and Beta Probes
 - ___ Chocks
- ___ Telemetry
 - ___ Recorder
 - ___ Tape
 - ___ TM Battery
 - ___ Recorder Battery
 - ___ Display Case
- ___ Video Recorder
 - ___ Camera Pack
 - ___ Tape
 - ___ Stopwatch
- ___ Transmitter
 - ___ Extra Battery
 - ___ Module
- ___ Cleaning Supplies
 - ___ Cleaner
 - ___ Paper Towels
- ___ Paperwork
 - ___ Flight Profiles
 - ___ Data Sheets
 - ___ Pencils
- ___ Air Pump
- ___ Fuel (2 gallons of 25%)
- ___ Starter Battery
- ___ Tool Kit
- ___ Starting Box
 - ___ Pump
 - ___ Starter
 - ___ extension
 - ___ bushing
 - ___ Glow Plugs
 - ___ Glow Plug Ignitor
 - ___ Exhaust Seals
- ___ Sound Attenuators
- ___ Donuts

FLIGHT TEST PROCEDURES CHECKLIST

WALKAROUND

Screws Tight
Surfaces Secure - no binding

AIRPLANE SETUP

Electrical Connections
Fuel
Canopy

TELEMETRY SETUP

Battery Installed
Tape Installed
Recorder Connected

PREFLIGHT CHECKS

TM Displays Active
Control Surfaces Active and Free
Range Check
Gear Pressurized and Working

Calibration

recorder on

<u>Control</u>	<u>1st</u>	<u>2nd</u>	<u>3rd</u>
AOA	down	0	up
Beta	right	0	left
Stab	down	0	up
Ail	down	0	up
Rud	left	0	right

(note: ensure all calibration points are toggled)

FLIGHT TEST PROCEDURES CHECKLIST(cont)

ENGINE START - (log battery)

ENGINE TUNE

DATA ON

HIGHSPEED TAXI TEST

FIRST FLIGHT - Fam for Don lasting five minutes / validate TM operation

DATA OFF

SHUT DOWN - BATTERIES OFF

FUEL - check level for max duration determination, then refuel

REPRESSURIZE LDG GEAR - if necessary

ENGINE RESTART - (log battery)

DATA ON

SECOND FLIGHT - Steady heading side slips

DATA OFF

SHUT DOWN

Post-calibration

recorder on

<u>Control</u>	<u>1st</u>	<u>2nd</u>	<u>3rd</u>
AOA	down	0	up
Beta	right	0	left
Stab	down	0	up
Ail	down	0	up
Rud	left	0	right

(note: ensure all calibration points are toggled)

BATTERIES OFF

SECURE

Date 20 July 1991

FLIGHT TEST DATA SHEET

Battery - Start 0820 Stop 0848
Previous 0 Duration +28 Cumulative 0+28

Flight No. 1 Purpose: Pilot Fam Flight

Takeoff: 0840 Land: 0848 Runs: ?

***** Note: DO NOT EXCEED 10 MIN OF FLIGHT *****

Comments: Flight went well. 1/2 tank of gas used over 20 min.

TM appeared to be working well. needles were giving good

indications. dead transmission times clearly evident. Engine ran

rough and quit as approach was made. Dead stuck w/o

complications

Press 29.98 in Hg /Temp 63 °F /Elev 134 ft /Wind 270-04 /Alt 050 ft

Battery - Start 0905 Stop 0935
Previous 0+28 Duration 0+30 Cumulative 0+58

Flight No. 2 Purpose: Steady-heading Side-slips

Takeoff 0927 Land 0934 Runs 8

***** Note: DO NOT EXCEED 10 MIN OF FLIGHT *****

Comments: Right rudder first 1, 2, 3 (full deflection)

Neutral on next pass 5

Left rudder next 5, 6, 7 (full deflection)

All conditions the same as last pass

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